ELECTROTHERAPY

JACOBY

A SYSTEM

OF

PHYSIOLOGIC THERAPEUTICS

A PRACTICAL EXPOSITION OF THE METHODS, OTHER THAN DRUG-GIVING, USEFUL IN THE TREATMENT OF THE SICK

EDITED BY

SOLOMON SOLIS COHEN, A.M., M.D.

PROFESSOR OF MEDICINE AND THERAPEUTICS IN THE PHILADELPHIA POLYCLINIC; LECTURER ON CLINICAL MEDICINE AT JEFFERSON MEDICAL COLLEGE; PHYSICIAN TO THE PHILADELPHIA AND RUSH HOSPITALS, ETC.

VOLUME I

ELECTROTHERAPY

BY

GEORGE W. JACOBY, M.D.

CONSULTING NEUROLOGIST TO THE GERMAN HOSPITAL, NEW YORK CITY; TO THE INFIRMARY FOR WOMEN AND CHILDREN; AND TO THE CRAIG COLONY FOR EPILEPTICS, ETC.

IN TWO BOOKS

BOOK I

ELECTROPHYSICS—APPARATUS REQUIRED FOR THE THERAPEUTIC AND DIAGNOSTIC USE OF ELECTRICITY

With 163 Illustrations

LONDON

REBMAN, LIMITED

129, SHAFTESBURY AVENUE, W. C.

1901

WM. F. FELL & CO.,
ELECTROTYPERS AND PRINTERS,
1220-24 SANSOM STREET,
PHILADELPHIA.

THERAPEUTICS WITHOUT DRUGS

A FOREWORD TO THE 'SYSTEM OF PHYSIOLOGIC THERAPEUTICS'

With the thorough work on Electrotherapy by Dr. Jacoby, supplemented by the excellent special articles of Drs. Da Costa, Jackson, Scheppegrell, Martin, and Ohmann-Dumesnil, begins the issuance of a series of volumes treating of much-neglected but important remedial measures. It is a work that I have long had in mind, and which, by a fortunate coincidence, had likewise been contemplated by my friend and publisher, Mr. Kenneth M. Blakiston. The system is the first of its kind to be published in America or in the English language, and in many important respects differs from similar works in other tongues. Among these differences are inclusion of themes, exclusion of irrelevant material, and general plan. In its planning, chiefly based on my observation of the needs and desires for information of students and practitioners, I have had the benefit of Mr. Blakiston's intimate knowledge of medical books, and in its publication the advantage of his personal supervision of the numerous minutiæ that go to make a book mechanically perfect, and thereby diminish the labor of the reader in consulting it. We take a just pride in the handy form and clear typography of the volumes.

Preferring compact books by single writers to bulky tomes of composite authorship, I have endeavored so to arrange the work that the entire field shall be covered, that nothing of moment shall be omitted, either from the general scheme or from the special articles, that theory and principles shall be sufficiently but briefly set forth, and that the descriptions of methods, indications, and counterindications shall be clear, definite, full, and practical; thus enabling the general practitioner to carry out for himself the important therapeutic measures recommended, and to do so understandingly and correctly.

As the system is practical rather than encyclopedic, history has received but the necessary minimum of attention, and references to literature are not frequent.

Each book, while complete in itself, also forms part of an organic whole, and has been written and edited with relation to its place in the system. Throughout the series the consideration of the special diseases for which particular measures are advised is preceded by a general study of the physiologic action and the therapeutic applicabilities of the remedial power giving the book its title.

In the concluding volume I purpose to set forth the general principles of what, in the absence of any better word, I have ventured to term 'Physiologic Therapeutics'; and to indicate the considerations that should guide the physician in the choice and application of the remedial means discussed in the special books. By way of preface, however, a briefer survey of the field may be taken, and some of its salient features pointed out.

Health is preserved, and when disturbed by what we are accustomed to term slight causes, is obviously restored by the automatic mechanisms of the human body. Life, according to Mr. Herbert Spencer, is characterized by the power of living beings to preserve a mobile equilibrium within their environments, or, as he phrases it, by 'the continuous adjustment of internal relations to external relations.' In order that this equilibrium of the organism as a whole may be conserved, it is necessary that there should be a like condition of equilibrium as between its different parts. In other words, a perfect balance of function must be maintained by continuous adjustment of internal relations to one another. The balance of internal relations, then, constitutes health; and during the long ages of evolution, the normal organism has acquired and developed, to a high degree, the power of restoring this balance, when disturbed, whether by intrinsic or by extrinsic causes, through its own automatic adjustments. Granting the absence of a preservative design, we must, nevertheless, recognize the preservative result of certain reactions to environmental or internal change; and it is in harmony with general biologic doctrine to believe that favorable variations in this respect have been perpetuated and intensified by natural selection. A striking instance of such preservative reaction is the production of

antitoxins, to whose therapeutic utilization we justly point as among the greatest scientific triumphs of the past century; while it is highly probable that allied processes of immunity, now nearing solution, and of which vaccination has been prophetic, will similarly be imitated by medical art in the early years of the present century.

Natural recuperative power has been developed, not through the intaking of substances foreign to the organism, but by physical, chemical, and, finally, psychic reactions of the cells, tissues, organs, systems, and—a factor not to be ignored—of the organism as a whole. Such reactions are in some instances simple, in others complex, involving numerous interactions. Nor can a sharp dividing-line, either as to origin or as to character, be drawn between those reactions of the organism to hostile changes in the environment, which we term morbid, and those which we designate as protective, salutary, or recuperative. As I have elsewhere said,[1] not only must we recognize that disease and recovery are alike vital processes in which the organism itself is the most active agent, and that neither morbific nor therapeutic influences endow the organism with new attributes or introduce into its operations new powers, but we must also keep in mind that disease and recovery are often, if not always, one continuous process. Upon the discussion of this intricate subject, however, I shall not now enter, but will merely emphasize the facts that a health-preserving and health-restoring tendency exists; that it is a natural endowment, and not the gift of art; and that it is dependent upon the inherent properties of cells, tissues, organs, and the organism. Some of these qualities are constantly manifested (or kinetic), and in the normal processes of recovery are merely modified—as, for instance, the thermic reaction, altered in the pyrexia of fever; while others, like the power of fibrinogenesis, manifested by blood-clotting, are latent (or potential), and are evoked only in reaction to perturbing influences. Salutary reactions, however, may be delayed, deficient, aberrant, or excessive; and thus art must come to the assistance of nature, and therapeusis finds its reason for being. All successful treatment, nevertheless, depends upon the evocation,

[1] "Some Thoughts Concerning Disease and Recovery in Their Relation to Therapeutics." Address before the Medical and Chirurgical Faculty of Maryland, Baltimore, 1896.

stimulation, and control of the recuperative reactions, together with the suppression, diminution, or neutralization of antagonistic reactions likewise occurring automatically as the result of extraneous morbific influences or of internal failures or disturbances.

The means for accomplishing these therapeutic ends fall into two great categories, which might be termed 'artificial' and 'natural,' were it not that both of these terms have certain misleading connotations. That which, for convenience, may be termed 'artificial therapeutics' consists in the introduction into the organism of substances ordinarily absent therefrom and, mostly, foreign to its composition, which, chemically and otherwise, provoke certain reactionary changes, and thus modify the recuperative or the morbific processes. This is the great and serviceable group of therapeutic means termed 'drugs,' the use of which it is not my purpose to antagonize or to decry. On the contrary, I have a robust faith in the power for good of the right drug, given in the right dose, at the right time, and equally in the power for harm of the wrong drug, the wrong dose, and the wrong time of giving. Nevertheless, a more restricted use may be made of drugs, with less danger of harm-doing by reason of mistake in the election of drug, dose, or time, by the physician who familiarizes himself with the powers of the remedial agents falling into the second group—that of 'natural' or 'physiologic' therapeutic means.

But all that exists in nature is natural—drug equally with sunlight, microbe equally with antitoxin; and, under all the circumstances, the disordered functions of the paralytic, for example, are equally physiologic with the co-ordinated functions of the athlete. Moreover, any intervention by the physician in a case of illness, be it merely to enforce rest, or to regulate diet, or to open the window of the sick-room, is an exercise of his art. It is evident, therefore, that for the purposes of our discussion some narrower definition must be given to these terms. By natural or physiologic therapeutics, then, is meant the utilization in the management of the sick of agencies similar to those constantly acting upon the human body in health; but, because of some departure from health, needing to be specially exaggerated or localized in their action.

Paradoxical though it may seem, this limitation of terms leads to

a broader outlook. Through it we are enabled to find a firm, scientific basis for hygienic and therapeutic traditions hitherto regarded as merely empirical.

Nor would I be misunderstood as decrying empiricism. Hippocrates, the empiric, was the father of scientific medicine; the dogmatists were his opponents, and dogmatism is still the enemy of medical progress. Rational empiricism in medicine consists in the orderly arrangement and analysis of facts observed not only in the laboratory, but also at the bedside; and in making, from the data thus established, inductions to the principles of science and deductions to the applications of art. In the experience to which rational physicians look, must be included the whole history of the human organism, and, indeed, so far as these can be learned, a study of the conditions that have affected the living matter before it was human; for in the actions and reactions of living matter with its environment, from the simplest to the most complex, are to be found the influences that have determined not alone the physiologic, but also the pathologic, development of man, together with the power of the organism to recover from the disturbance that we term disease.

Speculation upon the origins of living matter is enticing, but not profitable. Given the original living matter with its inherent forces and tendencies and in its aqueo-terraneo-atmospheric habitat, and its development into man, and man's coming into his present physical, mental, and moral condition are the resultants of habit and environment. Under these general heads are to be understood the effects of climate and of weather (including heat and cold, the physical and chemical constitution of the atmosphere, sunlight and other light, electricity, etc.), the use of water, food and methods of feeding, rest, and exercise of function, physical and mental; of which last, not the least important phase is one commonly overlooked—emotion. These and similar influences having helped to make man what he is, may well be employed to remake him when he departs from the norm.

The pathologic influence of emotion is well shown in the evolution of exophthalmic goiter and in the protean manifestations of hysteria. As psychic processes can share in the causation of disease, so may they be utilized to bring about recovery in carefully selected cases.

'Faith cure,' 'mind cure,' 'hypnotism,' and the like have a basis in the fundamental facts of human nature, and physicians should study and rightly use the therapeutic potency of suggestion, rather than suffer charlatans to abuse it.

Pneumatotherapy demands more attention than it has yet received in America. To refer to but a single phase of its usefulness, I would not wish to undertake the treatment of many patients with pulmonary tuberculosis, with asthma, or with some forms of chronic bronchitis, were I to be deprived of the use of compressed and rarefied air, though all the drugs past, present, and future, were freely placed at my disposal.

Climate has a vast range of therapeutic application, by no means confined, as many seem to think, to pulmonary affections; but it should be much more definitely prescribed than is the common practice, and with greater consideration of the patient's individuality and of the numerous details of daily life and of human needs and desires. For this reason much attention has been given in the volume on Climatotherapy to the description of the special features of individual resorts.

The use of cold water externally in the presence of fever is growing, thanks to Brand, Baruch, and their disciples, but hydrotherapy has other and even more important applications; and while, to secure the full benefit of its powers, apparatus more or less elaborate and special institutes are needed, and should be established by the profession in every important center, much can be done at the patient's home and in the physician's office by simple means easily accessible. The subject of balneology is partly climatic, partly hydrotherapeutic, and touches also on drug therapy. It is much to be regretted that comparatively so few of the numerous available springs in America have as yet been systematically developed; the references in this section are of necessity largely to European resorts.

The great influence of diet upon the human being in health and in disease warrants the devotion of a book to that topic, and herein the important internal uses of water are again emphasized.

Recent developments point to a wider use of dry heat, of sunlight, and of various forms of artificial light and other radiations in the treatment of local and nutritional disorders. These subjects are

considered in appropriate connections; the Röntgen rays, in the volume on Electrotherapy.

In the judicious alternation of rest and exercise, applicable not alone to the amelioration of neurotic or debilitated states, but also to nearly all metabolic affections, one finds a method of treatment in harmony with the rhythmic alternations in nature. The now justly celebrated 'Nauheim' or 'Schott' methods for the treatment of cardiovascular disorders by means of thermal, saline, and carbonated baths, and gentle resistance exercises, afford a combination of the advantages of water, heat, mineral baths, and mechanical measures, whose striking results are but illustrations of what can be accomplished for the relief even of patients affected with serious organic lesions, without the use of drugs.

And, so, examples might be multiplied; but sufficient has been said to indicate the wide scope and the great power of the group of remedies considered in the 'System of Physiologic Therapeutics'; remedies that have been employed and advocated, though perhaps not always with sufficient insistence, by the great teachers of medicine from Hippocrates to our own contemporaries.

But if the treatment of disease be important, its prevention is even more so, and the measures that best assist recovery will, if applied in time, best strengthen the organism to resist morbific influences. Modern science, however, goes still further, and, having discovered the exciting causes of many special diseases and disorders, as well as the manner of their transmission and propagation, enables us to attempt the prevention of such diseases by the destruction or exclusion of the agents of infection.

One of the volumes of this system is appropriately devoted to hygiene, personal, domestic, civic, and national, and to that care of the sick-room wherein prophylaxis and therapeusis meet, if indeed they are ever separated.

Professional tradition has given us a few remedial measures upon the border-line between medicine and surgery, much abused in older days by undue employment, much abused in latter days by undue neglect and vilification—blood-letting, poulticing, counterirritation, and the like. Experience proves that these measures have a definite sphere of usefulness, and they are treated in an article of the conclud-

ing volume of the series. Such other matters as seemed not of sufficient extent to demand the devotion of a separate book are likewise considered in that volume. There serotherapy and organotherapy find place, and their established powers and probable enlarged future usefulness are set forth. The digest by Dr. Augustus A. Eshner, which is to be found in the same volume, represents but a part of my indebtedness to his professional and literary attainments and friendly counsel.

SOLOMON SOLIS COHEN

1525 WALNUT STREET, PHILADELPHIA,
March 11, 1901.

PREFACE

The number of existing books upon electrotherapy is already so large that the need of another may be questioned, and I certainly should not have undertaken the arduous task of rearranging and restating well-known facts were the book not to be what it is, a part of a system of extra-medicinal therapeutics.

Electricity certainly merits as much consideration in our treatment of disease as do other nonmedicinal methods. So the book had to be written, and believing, as I do, that there must be some radical defect in the usual manner in which the subject is presented to account for the generally deplored fact that medical students pay so little attention to the study of electricity, I have endeavored to be governed by the following considerations :

1. Electricity from day to day acquires more and more importance scientifically and practically. The industrial supremacy that it has attained is due to a thorough knowledge of its fundamental laws. These laws must form the basis of all therapeutic knowledge ; yet many of the books upon electrotherapy are replete with errors and contradictions, while they are lacking in precise statements. A knowledge of the fundamental laws, the ability to use instruments in their application, and a precise idea of the meaning of the expressions employed, are therefore essential prerequisites for every physician who desires to utilize electricity as a remedial agent.

2. The theory of explanation of the phenomena observed should be the one-fluid theory. This theory fully explains all phenomena, is much simpler than the two-fluid theory, and is the only one that is convenient in the discussion of dynamic electricity.

3. Students of medicine and physicians in general evince a distaste for all mathematical demonstrations and technical explanations, and, accordingly, while neither one nor the other can be ne-

glected entirely, it is possible to simplify them and reduce them to a minimum.

4. Physiology and diagnosis are the direct supports of all therapy, and to this rule electrotherapeutics forms no exception.

5. In the employment of all remedies a certain degree of empiricism is unavoidable; perhaps it is more dominant in the field of electrotherapy than elsewhere, and thus has led to ultra-skepticism and ultra-optimism, both of which are deprecable. The more simplified the methods of treatment become, the more will the entire subject be denuded of the mysticism that has hitherto surrounded it, and the more shall we realize what can really be accomplished.

References to literature, and in many cases even to the sources from which commonly accepted facts have been taken, have been purposely avoided. A full tabulation of the literature of the subject up to 1895 will be found in E. Remak's "Grundriss der Elektrodiagnostik und Elektrotherapie."

Much here presented has been drawn unreservedly from one or more of the following sources:

Biggs, C. H. W., "First Principles of Electricity and Magnetism," London, no date.

Singer, Ignatius, and Berens, Lewis H., "Some Unrecognized Laws of Nature," New York, 1897.

Stintzing, R., chapter on the Electrotherapy of Diseases of the Nervous System, in "Handbuch der Therapie innerer Krankheiten," Penzolt und Stintzing, Jena, 1898.

Houston, E. J., and Kennelly, A. E., "Electricity in Electrotherapeutics," New York, 1898.

Cohn, Toby, "Leitfaden der Electrodiagnostik und Electrotherapie," Berlin, 1899.

Hedley, W. S., "Current from the Main," London, 1898.

Laquer, Leopold, chapter on Electrotherapy in "Lehrbuch der allgemeinen Therapie," u.s.w., Eulenburg und Samuel, Berlin und Wien, 1898.

Other and older books, many journal articles, and various instrument makers' catalogues have been consulted. The latter, especially those of W. A. Hirschmann, Flemming, Reiniger, Gebbert, & Schall, Waite & Bartlett, and McIntosh Battery Company,

have supplied me with many necessary illustrations, while the drawings for a large number of illustrations had to be specially made.

The growing importance, as a source of electricity for medical work, of the currents supplied to modern houses for light and power, warrants the somewhat extended consideration given to the methods by which these currents may be utilized with safety.

The book, all in all, will serve as a guide for further study, yet chiefly, I hope, as an incentive to practical work, for it is my belief that from no book can the employment of electricity be learned satisfactorily.

No one can be more cognizant of the defects of the book than am I, but I feel certain that these defects will be least emphasized by those who have, at some time, been called upon to perform a similar work.

GEORGE W. JACOBY

605 MADISON AVENUE, NEW YORK,
September 1, 1900.

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A System of Physiologic Therapeutics

ELECTROTHERAPY—BOOK I

Part I

ELECTROPHYSICS

A SYSTEM OF PHYSIOLOGIC THERAPEUTICS

ELECTROTHERAPY

PART I

ELECTROPHYSICS

CHAPTER I

FUNDAMENTAL CONCEPTIONS

Electric Vibrations. Correlation of Energy. The One-fluid Theory. Unity of Electricity. Excitation. Friction. Contact. Attraction and Repulsion. Positive and Negative. Conduction. Insulation. Density. Tension. Influence. Quantity. Electrometer. Potential. Capacity. Condensation. Electromotive Force. Methods of Producing Electricity.

Our conceptions of **the nature of electricity** are very obscure, and we are to a large extent in ignorance concerning it. We know that what we call electricity will decompose water, heat a wire through which it flows, deflect the compass needle from its north-south position of rest, and that each time we interrupt the flow of electricity at any place a spark is produced; but what it is that causes these effects we do not know. This ignorance is due to a certain extent to our forced endeavor to consider electricity as an entity—as a distinct form of energy.

If, however, we would but look upon electricity simply as a further manifestation of natural force developed through molecular motion, we should at any rate obtain a less hazy idea of its nature. Nevertheless, we should still be in the region of hypothesis, rather

than in that of demonstration. In short, our knowledge of electricity is obtained from its effects alone.

At present we know, through Mayer's and Joule's demonstrations, that chemism, heat, and light, the three great forces of nature, are directly interchangeable as to direction and rapidity of the molecular vibrations. This is easily demonstrated in regard to light and heat by a piece of metal the temperature of which is being raised. At first the vibrations caused by the heated metal are slow and in a vertical direction; as they become more rapid, the metal appears to give out light or, as we commonly say, becomes red-hot. As the heat is increased, the molecular vibrations become still more rapid; and in part changing their direction from vertical to horizontal, produce a white or bluish light, which indicates the so-called white heat.

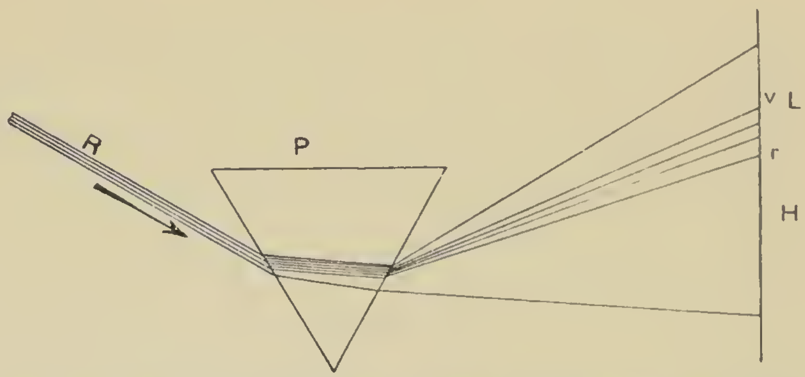

Fig. 1.—Analysis of Solar Light by a Prism, Showing the Heat, Light, and Actinic Areas of the Spectrum.

Now, this progressive change cannot fail to remind us of the solar spectrum; here also we have the color varying from red to the deep blue or violet. This, however, is only the visible spectrum. In the analysis of solar light by a prism we get three distinct and separate areas, as shown in figure 1.

First there is the central or visible portion of the spectrum, which begins with the dark red and ends with the ultra-violet. This is, however, really the smallest portion of the spectrum. Above the violet, extends an invisible area three times the length of the visible portion, which is significant on account of its power to bring about chemical action; while below the red, an area in which heat is developed extends ten times the length of the visible spec-

trum. For convenience we speak of the thermic, luminous, and actinic rays of the spectrum, and these merge so closely one into the other that it is difficult to define their limits. It has always been easy to reproduce the heat and the light areas of the spectrum; but of the ultra-violet or chemical area, although recognized, little was understood until recently, when, through the discovery of Röntgen, this portion of the spectrum has been reproduced in the X-ray. Thus we have light proper as an intermediary between heat and the so-called X-ray, and these three forces are all recognizable by their effects only. So, too, electricity is known from its effects alone, and these effects are interchangeable, so that under certain conditions we can derive from them heat, light, and chemical action. It would not be going too far, therefore, to consider electricity as a form of molecular vibration, and add it to make a series with our other natural forces. In the order of the rapidity of vibration our new table would read: heat, light, X-rays (or chemism), and electricity.

A few fundamental experiments will also teach us that: (1) The electric state is one of relativity only; (2) electricity is due to the equalization that takes place between two bodies in different degrees of excitation; (3) the excitation of such bodies differs only in degree and not in kind.

While our conception of the nature of electricity may be considered assumptive and theoretic, we are by no means lacking in positive knowledge concerning its actions and the laws that govern them. On the contrary, our knowledge in these directions is so precise and extensive that it may be questioned whether there is any probability of its being broadened. Let us, therefore, begin our investigation of the therapeutic possibilities and uses of electricity with a study of these effects and laws; confining ourselves for the most part to positive knowledge, but making use of theory whenever it will render the facts more easily comprehensible.

The earliest ideas of electricity were derived from the effects observed when one substance was rubbed against another, and in order, therefore, to gain a knowledge of the effects upon which our assumption of electricity is based, let us take up the earliest evidences that we are pleased to call electric.

Phenomena of Electrification.

Excitation.—We all know that when certain substances, such as amber, glass, sulphur, hard rubber, are rubbed with some other substance,—as, for instance, a piece of silk,—both substances acquire the property of attracting light bodies, such as shreds of paper, when brought near to them. The rubbed substances are said to be *electrified*, and the property that thus becomes manifest and whose cause is unknown is called *electrification*.

This property may also be acquired by placing a nonelectrified body in contact with an electrified one; it may then easily be seen that the previously electrified body has lost part of its electrification, inasmuch as it attracts light bodies with less force. Electrifica-

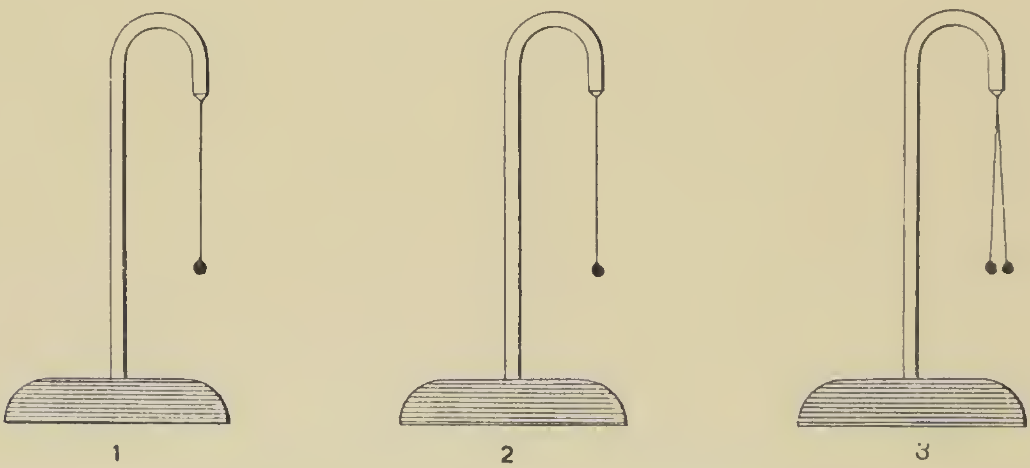

FIG. 2.—ELECTRIFICATION OF PITH BALLS.

tion is best studied as follows: Take three glass standards (Fig. 2) bent in the shape of a Roman "ſ," and fixed in wooden or metal bases. We will call them 1, 2, 3. From 1 and 2 suspend single small balls of elder pith by fine silk threads, so that they hang perfectly free, and from 3 suspend in the same way two balls so that they touch each other. In addition to this take a rod of glass a few inches long, a stick of sealing-wax, and a piece of silk. If we rub the glass or sealing-wax briskly with the silk and hold it close to the ball of No. 1, the ball will be attracted to the rod; but so soon as it has touched the rod, it will be repelled. Rub the rod again and hold it to the pair of balls of No. 3, and they will be attracted as was the single ball, and on removing the rod after the

balls have touched it, they will come to rest; not, however, resuming their position of contact, but standing off at a distance from each other. Bring No. 1 and No. 2 near each other. Touch No. 1 with the rubbed glass rod and No. 2 with the rubbed sealing-wax. The two balls will now attract each other, but if they are allowed to touch, they will fall apart again and lose all sign of electrification.

These phenomena are designated as *electric*, and the agent producing them is termed *electricity*. How this agent should be looked upon we have seen, but there are, as will be shown later, certain conveniences in speaking of it as a *fluid*, and so long as we know that this term is used merely for the purpose of comparison and continue to bear this in mind, there can be no objection to its use.

Conduction.—When a scrap of paper is attracted to a rubbed rod of glass and remains attached to it, this scrap acquires the power of attracting a second piece, this in turn of attracting a third, and so on. The electric state has therefore been *conducted* from the first scrap to the second, from the second to the third, etc. In certain substances it will also be found that by both methods of electrification, friction as well as contact, the acquired property may *remain localized* at the point rubbed or touched, or it may *spread over the entire surface* of the body. Hence bodies have been classified as *good* or *bad conductors* of electricity, as, analogously, bodies may be good or bad conductors of heat.

If we examine the various substances as to their power of conducting electricity, we shall find many—for instance all metals—that are such good conductors that they at once discharge their electricity, while others are such poor conductors that they entirely oppose the spread of electricity; the latter are called *nonconductors* or *insulators*. Such are the resins, oils, etc. Between the two classes, conductors and insulators, there exists a class of *semiconductors* that require more or less time in order to conduct electricity. Dry air is a good insulator: as the moisture of air increases, its conductivity increases. This difference in the conductivity of various substances explains why certain substances—as, for instance, metals—cannot be electrified unless certain precautions are taken; for if they are held directly in the hand, the electricity

produced in them is at once conducted through the body of the operator to the earth, where it is spread over an infinitely large surface and is lost. For this reason the earth may be looked upon as a large reservoir, and every body that is placed in a state of good conduction with the earth will lose its electricity, while if it is placed in a state of bad conduction, by interposing a bad conductor between the electrified body and the earth, the electricity will be retained. If, therefore, we desire to retain the electricity upon a conductor for a time,—as, for instance, upon a hollow ball,—we must insulate the ball by attaching it to a bad conductor, as a glass or resin rod, and, furthermore, endeavor to have the surrounding air as dry as possible. Thus poor conductors are utilized to insulate good ones; but it must not be forgotten that no conductor or insulator is perfect.

Every insulated body may be electrified by friction as well as by contact. There are also other ways of effecting electrification besides those of rubbing dissimilar substances together or placing dissimilar substances in contact directly. Those most used are by making the contact of dissimilar substances through an intermediary, as by placing these substances in a liquid; by warming or cooling the junction of two dissimilar substances; by making changes in a system of magnets and wires, either the strength of the magnet or the relative position of the magnets and wires being altered.

Unity of Electricity.

No matter how produced, electricity shows the same qualities, although these may differ quantitatively. There is but one electricity. Whether we produce it through the friction of dissimilar substances (frictional electricity), or by the immersion of two dissimilar substances in a fluid (galvanic electricity), or by soldering two pieces of different metals together at two different places and then heating or cooling one metal (thermo-electricity), or if we effect the changes previously spoken of in the system of magnets and wires (magneto-electricity), the electricity is always one, and its actions are always the same. Of these actions we shall speak later; let us confine ourselves for the present to the effects already observed in our pith-ball experiments,

in order, if possible, to explain the theory of the nature of the force that produces these effects.

The **theory of Symmer**, which assumes the existence of two electric fluida and explains all the electric phenomena by the assumption that an attraction takes place between the molecules of these electric fluida and the molecules of matter, similar electric molecules repelling each other, dissimilar ones attracting each other, but in both cases dragging away with them the molecules of matter, has been abandoned by electricians ; yet, strange to say, it has been retained by nearly all writers on medical electricity. The two-fluid theory must give way to the **one-fluid theory of Franklin**, to the elucidation of which we shall confine ourselves.

We must accept the fact that electricity exists in all bodies, in space, and in the earth, its quantity being determined in each case by the circumstances under which it is found. The constant quantity may be considered as a standard or normal quantum of electricity. As the result of certain interactions with other bodies, a particular body may contain more or less electricity than this normal quantum. In the first case we say the body has a plus of electricity, or is positively electrified; in the second case, that it has a minus of electricity, or is negatively electrified. These differences correspond to the various modes of electrification that we have already described. Arbitrarily we assume that the glass that has been rubbed with the piece of silk has been positively electrified. As a matter of fact, it is totally immaterial whether we assume that it has received a plus or a minus of electricity, for this "more" or "less" is simply relative to the quantity of electricity contained in the surrounding objects.

Furthermore, we must recognize that electricity seems to move with facility in certain bodies that we have designated as good conductors, while in those that are bad conductors its movement meets with a great resistance or opposition. Also must we admit that electricity seems to have an effect on electricity at a distance, the action being similar to attraction and repulsion. Of course, we do not actually acknowledge action at a distance. We must imagine that the presence of electricity at a certain point in some way modifies the surrounding medium, which, thus altered from particle

to particle, in its turn acts upon the electricity placed at some other point. This being understood, we may suppress the intermediary vehicle and reason as though we had an action at a distance.

By this hypothesis the general facts can easily be explained. If a body contains the normal quantity of electricity, no action will be noticed in the neighborhood of this body. If, however, its electric content be altered, then such alteration will also change the reciprocal actions of the electricity contained in the body, of that in the surrounding medium, and of that in neighboring bodies. This change may be effected in various ways:

1. By some action, mechanical, calorific, or chemical, between **two nonelectrified bodies.** One of the bodies thus receives more electricity than it had and becomes positively electrified; this, however, can occur only if the other body loses electricity and becomes negatively electrified; in other words, the bodies under such circumstances become *electrified oppositely.*

2. A nonelectrified body is brought **in contact** with a body electrified positively or negatively (plus or minus); in the first instance the electrified body gives up a part of its electricity in order to arrive at a state of equilibrium; it becomes less completely electrified, but the other gains what this one loses, and consequently it must become electrified positively. The process is reversed in the opposite case. Thus the charge is always of the *same sign* as that of the charging body.

Attraction and repulsion, which are exerted between bodies with contrary or similar electrification, may also be explained satisfactorily by this one-fluid theory; the essential is that the bodies are differently charged—that is, that they contain different quantities of electricity; and such attraction of unlikes or repulsion of likes will be proportional to the quantities of electricity present.

Density or Distribution of Electricity.—Electricity gathers on the *surface* of objects, as can be seen from the following simple experiments. Take an insulated brass ball, such as A (Fig. 3), that has a metal covering, C, fitted carefully around it, but in two halves, so that it may conveniently be removed by means of the insulating handles, B, B. Place the covers over the ball, and

charge the whole apparatus with electricity. Then remove the covers C, C, and all of the charge will be found upon them, while the ball A will have no charge whatever; thus showing that the whole charge was distributed over the surface.

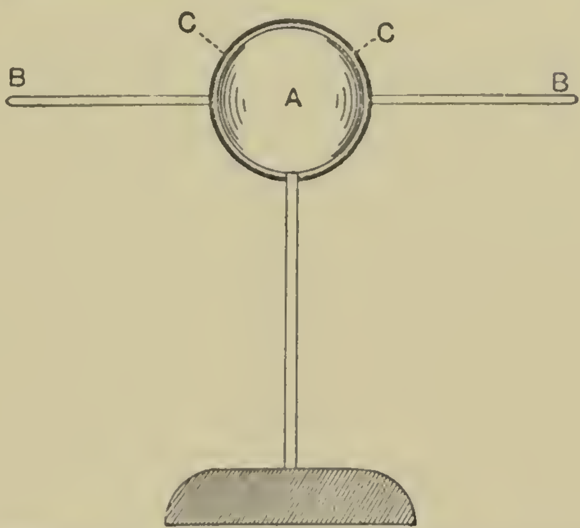

FIG. 3.—SPHERE SHOWING THE ACCUMULATION OF ELECTRICITY ON ITS SURFACE.

Since electricity distributes itself over the surface of a body, the same quantity of electricity distributed over a small surface will necessarily be more **dense**, more compact, than if spread over a large surface. Thus upon a sphere the density will be equal at all

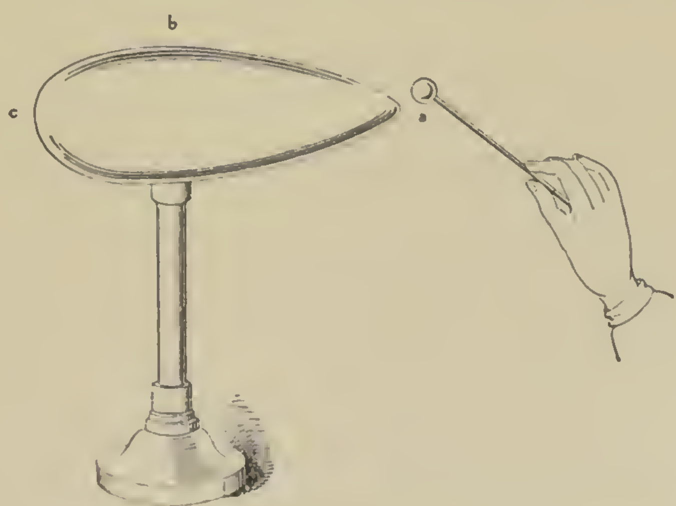

FIG. 4.—OVOID SHOWING DISTRIBUTION OF ELECTRICITY.

points, while upon an ellipsoid the density varies at the different points. In figure 4 the greatest density would be found at "a," the least at "b," and an intermediary state of density at "c."

The greater the density of electricity, the greater will be its **tension**—that is, the tendency of electricity to overcome the resistance of the air, until finally, this resistance being overcome, the electricity escapes. If the escape occurs in the dark, it appears luminous.

Electrification by Influence.

Induction.—When an electrified body is placed in the vicinity of other bodies, insulated or not, it sets up in these other bodies electric modifications—*i. e.*, variations in the distribution of electricity; thus it acts upon them by influence.

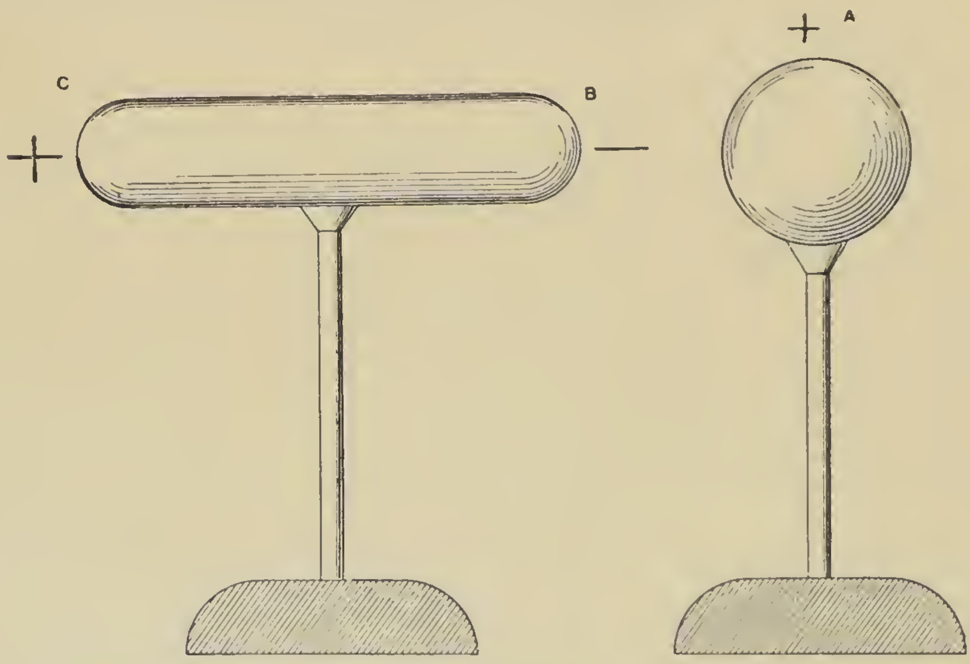

FIG. 5.—SHOWING THE ACTION OF AN ELECTRIFIED ISOLATED CONDUCTOR UPON A NONELECTRIFIED ISOLATED CONDUCTOR.

While it, however, is influencing the other bodies it is also being influenced—its repartition of electricity is being altered. We are dealing with the distribution of electricity in a system of neighboring bodies. Thus we have (Fig. 5) an isolated conductor, B C, and a ball, A, positively electrified, which we approach to a certain distance of each other. The equilibrium existing in the body B C will be disturbed, and on account of the repulsion exercised by A there will be produced a movement of electricity from B toward C, thus causing a deficit at B and a surplus at C. There will thus be at the point of the conductor nearest to the influencing body a contrary

charge to that of this body, and at the most distant part a similar charge. This phenomenon is sometimes termed **induction.**

The result would be analogous if, instead of a positively charged body, A, we were dealing with one negatively charged. If A is removed or discharged, every action of influence ceases immediately, and B C returns to its primary unelectrified state.

Charging by Influence.—If B C (Fig. 6), instead of being insulated, is in communication with the earth, the effect exercised by A will be the same in a general way, but on account of the connection with the common reservoir, the earth, the only demonstrable change will be that at B, which will be opposite and contrary to A. In this

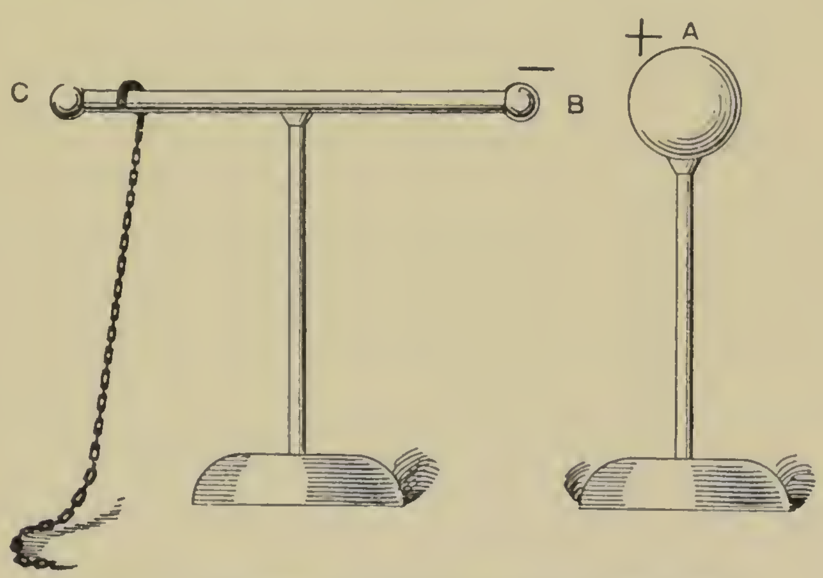

FIG. 6.—SHOWING ELECTRIFICATION BY INFLUENCE.

case the charge at B is greater than in the former experiment. If A is now removed or discharged, the body B C will return to its unelectrified state. If, however, before so removing the body A the communication between B C and the earth is broken, the former (B C) will retain the charge that it had acquired in consequence of the action of A.

This fact is very important, for we thus have another mode of producing electrification; and it will be noted that, contrary to electrification by contact, here the conductor B C receives an opposite charge to that of A, while A suffers no modification of its own charge.

The **attraction and repulsion** of light bodies are dependent for the most part upon this influence action, and the phenomenon represents the endeavor of the bodies to regain and maintain their electric equilibrium. If two bodies are dissimilarly charged, they try to approach each other in order to neutralize themselves, and thus apparently **attract** each other. If, however, they are similarly charged, they separate in order to prevent their condition becoming one of more unstable equilibrium by a higher charge. This is **repulsion.**

These phenomena of influence are manifested in the mode of action

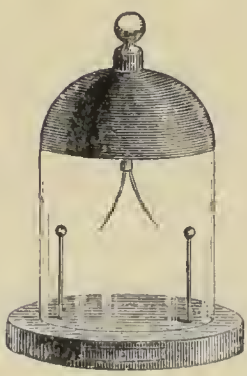

Fig. 7.—Gold-leaf Electroscope.

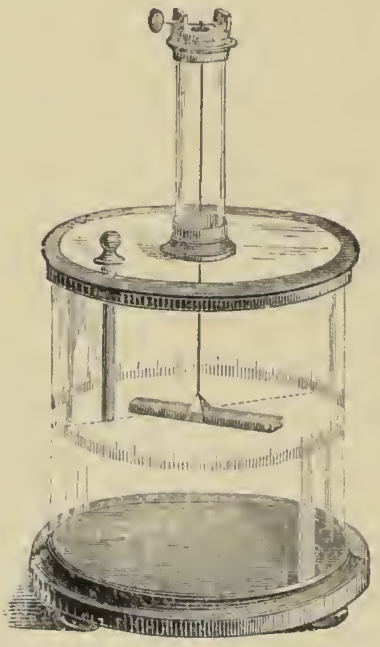

Fig. 8.—Electrometer.

of **the electroscope,** an apparatus employed for the purpose of discovering whether a body is electrified, and determining the (+ or —) nature of its charge. The gold-leaf electroscope is most used (Fig. 7). It consists of two narrow strips of gold-leaf pasted to the end of a metal rod, the other end of which is so fastened into the cupola of a bell glass that it passes through the glass to the outside and ends in a free knob. The gold-leaf strips hang free in the center of the glass. The bell glass not only protects the gold-leaf strips from currents of air, but also directly insulates them against surrounding objects. If the knob of such an electroscope is touched by an electrified body, the strips of gold-leaf diverge.

A modified electroscope serving for the measurement of the quantity of electricity is called an **electrometer** (Fig. 8).

Charge.—In any electrified body there is a certain amount of electricity that can thus be measured, and this we call its quantity, or **charge** of electricity. It must be borne in mind that whether the charge be large or small in a given body depends solely on the quantity of electricity, and not on the size of the body. Thus, two bodies of different sizes having the same charge have each exactly the same quantity of electricity, and not differing quantities proportional to their size.

Potential.—Two bodies are said to be of the same **potential** if, when connected by a wire conductor, no modification of their electric condition takes place. If such a modification does take place, they are said to be of different potential, and by agreement the body that gives up its electricity is said to be of a higher potential than the body that receives it. For purposes of comparison **the earth** is considered to be of **zero** potential, and all bodies from which the electricity flows to the earth, or, in other words, that when connected with the earth lose electricity, are said to be of a positive potential; while, on the other hand, all bodies to which electricity flows from the earth, or that gain electricity when connected with the earth, are of a negative potential. Hence the potential of a body, irrespective of the size or nature of the body, is its degree of electrification above or below that of the earth. A practical conception of these facts may be obtained by instituting a comparison between electricity and water. Thus, if we wish to produce a flow of water from one point to another, we must make the point from which the water is to flow, higher than the point to which it is to flow. It will be seen that potential is not the same as quantity.

Capacity.—The **electric capacity** of a body may be considered to be the greatest quantity of electricity that may be acquired by that conductor. The same quantity of electricity communicated to different bodies does not necessarily bring them to the same potential; different bodies have a different electric capacity, and we may have a large electric capacity and yet a very low potential, and vice versâ. This capacity may be gauged by dividing the quantity

of electricity given up to a body by the variation in potential that it has undergone; thus, if C equal capacity, Q equal quantity, and V equal variation in potential, then $C = \frac{Q}{V}$.

The capacity of a body depends not only upon the surface of the body, but also upon those bodies that are in its immediate vicinity.

Charging and Discharging.

As already stated, when a body is electrified, it is said to receive **a charge** of electricity, or, more briefly, to be charged.

Charging consists in a disturbance of the normal electric equilibrium of the body charged, which thus passes into a state of higher or lower potential. If the potential be raised, the body is said to have received a positive charge, and if the potential be lowered, the charge is termed negative.[1]

The electrified body is thus in a condition to manifest electromotive force under favorable circumstances by **discharging itself** of its electric tension, and returning to its former state of equilibrium.

Discharge may be partial or complete, sudden or prolonged. A charged body may yield up at once its entire excess of electricity, and thus become nonelectrified; or it may yield up this excess (or charge) in successive portions, and thus become by degrees less and less electrified, until finally it becomes neutral again.

Only insulated conductors can receive and retain charges. If an insulated conductor charged with electricity be approximated to an insulated conductor not so charged, influence becomes established, and contrary states of electric potential manifest themselves at the points of the conductors that are nearest to each other; the nearer the conductors are brought together, the more does the one influence the other, and thus the greater will be the tendency to equalization; this tendency to equalization, or

[1] It may do no harm to repeat here, what has been said before, that the terms "high" and "low," "positive" and "negative," are relative and arbitrary; and that although the terminology and hypotheses of the one-fluid theory have been adopted throughout this book for the sake of clearness and simplicity, the author and the editor both regard electric energy as the analogue of light energy and of heat energy, and therefore as the concomitant of a special mode of molecular motion.

tension, may become so strong as to overcome the resistance furnished by the intermediary body of air, and a discharge takes place, accompanied by the phenomena of manifest heat and light.

If the charge of the electrified conductor be susceptible to instantaneous and continuous renewal, there will be a constant and steady equalization, manifested by a series of rapidly succeeding sparks, known as the **voltaic arc**; but if the charge be not so renewed, or be renewed but slowly, the results will vary in accordance with the shape of the conductors and the resistance that the air interposes.

Should one or both of the conductors be pointed, electric equilibrium will become established slowly; but if no such point exists, the return to equilibrium is sudden, manifests itself by a spark, and is known as a **disruptive discharge.**

In the first case, if one of the **conductors be pointed** and its electric tension becomes very great, equalization soon sets in and continues until an equilibrium with the surrounding bodies has been established. This phenomenon takes place gradually, and is accompanied by manifest light, which, however, can be observed only when other light is excluded. This form of discharge is known as the **convective discharge**, or electric spray.

On the other hand, if the conductors have **no point,** but the distance between them be sufficiently small, the electric discharge will be sudden, and the equalization will take place in the form of a **spark**; and this spark will be manifested by a zigzag line of light, accompanied by a more or less sharp noise or crepitation, and requiring but an incalculably short time for its transmission between the conductors.

The **intensity of the electric spark** depends upon the quantity of electricity. When this is great, the effects may be enormous, as is evidenced in the discharge of an electric cloud; here the manifest light of the spark is called lightning, while the noise or crepitation is known as thunder.

Conductive Discharge.—We have seen what takes place between two bodies in unstable electric equilibrium when brought near to each other but still withheld from actual contact by the interposition of a nonconducting medium or **dielectric** (usu-

ally the air) across or through which influence (induction) is manifested. If, now, these two bodies be connected by a conductor, the equalization of potential from the charged body to the uncharged one will take place along the conductor, and a **current** will pass. The current will continue to pass along the conductor so long as the charged body continues to give up electricity to the uncharged body, or until an electric equilibrium has been established. When one body discharges its electricity to another body through a conductor, as just described, the process is known as a **conductive discharge.**

Condensation of Electricity.

When an insulated body is connected by a wire with any source that furnishes electricity at a certain potential, the body will become charged until it has attained the same potential as the source; the quantity it receives depending upon its capacity. When an equilibrium has been established, the body is said to be completely charged. If, now, another conductor that is in connection with the earth is brought near this charged body, the potential of the charged body will become lessened, so that if it is again placed in contact with the source of electricity, it will receive an additional charge before a state of equilibrium becomes again established through its having again attained the potential of the source. By the near presence of a grounded conductor the capacity of the body has been increased, or, what is the same, the quantity of electricity necessary to charge the body completely is greater now than it was in the beginning. It is therefore said that here electricity has been **condensed,** or that we have effected a condensation of electricity.

Electromotive Force.

There is an inherent force that starts the current of electricity and maintains it; this is really the effect of the difference of potential between two bodies. No machine—and we refer to the friction machine as the one with which the student is most familiar—produces electricity directly, but simply effects a difference in potential and thus gives rise to a force that will be manifested as tension or, under suitable conditions, exerted in the production of an electric current. It is a force that tends to set electricity in motion, and is therefore called **electromotive force** (E M F).

Tension, potential, and electromotive force are thus closely related terms; tension referring to the state of the hypothetic electric fluid and potential to the relation between electrified bodies, due to the greater or less tension under which their contained electricity exists; this in turn depending upon the relative strength of the forces tending to move it and to oppose its motion. Thus, electromotive force bears the same relation to electricity that pressure does to water; and similarly as we speak of negative pressure in the case of a vacuum pump or negative quantities in mathematics, so we speak of negative potential or negative charge in the case of certain electric phenomena. It will be necessary to refer again to these terms and to consider the designation pressure in a more detailed manner.

No electric action can be produced without a prior production of electromotive force, and this force will produce electric action under favorable conditions, while under unfavorable ones it will not. An electromotive force may practically be produced for medical purposes in three different ways:

1. By the action of mechanical energy (frictional machine, electrostatic induction machine, dynamo-electric machine).

2. By the action of radiant heat (thermo-electric cell).

3. By chemical action (voltaic or primary cell, charged storage or secondary cell).

As the character of the electromotive force may be variously altered, and as such alterations play an important part in the use of electricity in diagnosis as well as in therapeutics, it will be more practical to study the methods of production of electromotive force, together with the laws that govern the flow of current, and then to treat, purely arbitrarily—

1. Frictional machines—frictional electricity.
2. Galvanic or primary cells—galvanism.
3. Induction machine—induced or faradaic electricity.
4. Thermo-electric machine—thermo-electricity.

After we have considered the foregoing, we shall be able better to understand the alterations of electricity—viz. (1) currents of high frequency and (2) sinusoidal currents and apparatus.

CHAPTER II

FRICTIONAL (STATIC) ELECTRICITY

Friction Machines. Cylinders. Plates. The Electrophorus. Influence Machines. Condensers. Fulminating Pane. Leyden Jar.

Electricity produced by friction may be obtained through a number of devices. Such a device, as first constructed by Otto von Guericke, represents the earliest **friction machine.** This consisted of a sphere of sulphur, which was rotated and against which the hands were applied; a metal chain suspended from the ceiling by insulating silk cords formed the conductor upon which the electricity was gathered.

Later, in 1708, Hawksbee substituted a glass globe for the sulphur sphere, and Bosc, in 1745, made use of silk to rub the glass. Next a cylinder of glass rubbed by a cushion was employed, and finally a plate of glass was substituted for the cylinder. Such a simple plate machine is shown in figure 9.

Here a plate, G, is made to revolve between two insulated uprights, A, B; a third upright, C, carries a rubber made of leather and amalgam, which presses against the glass plate when this is revolved by means of a crank handle. Another upright, D, carries a conductor, E, to the end of which, nearest the glass plate, are attached two combs, one on each side of the plate. The leather cushion of the upright, C, is now grounded by means of a chain. When the glass plate is revolved, both the amalgamated cushion and the glass plate become electrified. The cushion, however, being in connection with the earth and thus a part of it, will be raised only to the potential of the earth; while the glass will be brought to a higher potential—that is, receive a plus of electricity, or become positive. On account of the slight conductivity of the glass, this plus of electricity will not spread over the surface of the plate, but will remain at the point where it is produced until, by revolution of the

plate, it is brought opposite to the points of the combs, where it will be collected and will flow into the conductor, E. The plate being freed from electricity, will again become electrified when the other half passes between the cushions. Thus the circle is kept up, electricity accumulating on the conductor, E, and the quantity increasing until the loss of electricity through the air, which loss also augments equally with the charge, is exactly equal to the quantity furnished; then a condition of equilibrium will have been established. The necessity of establishing the connection between the rubber and the earth is easily understood; for were the cushion insulated, only a single charge could be obtained and

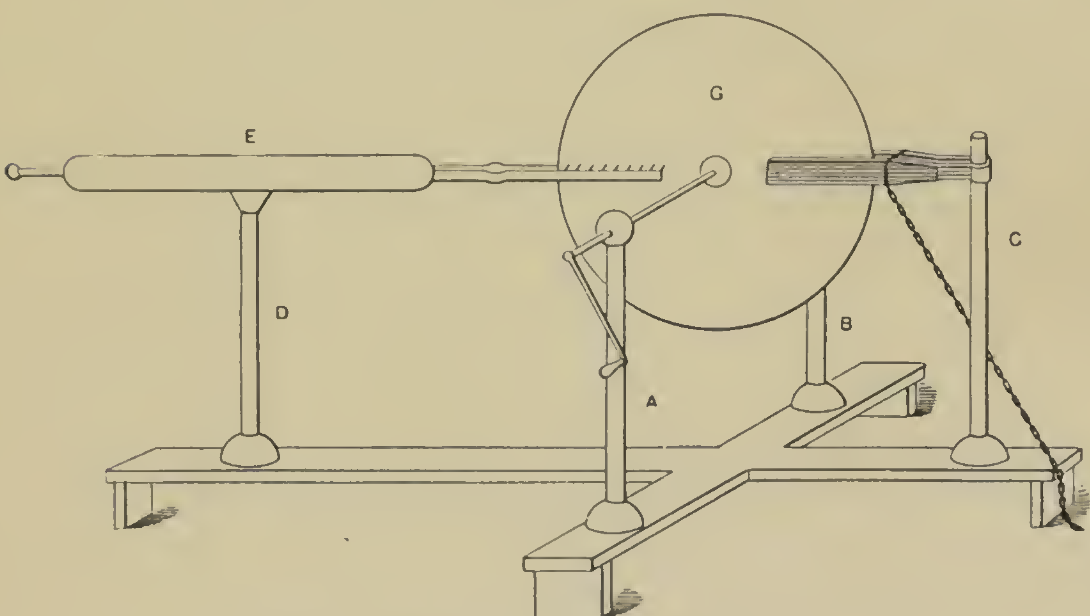

FIG. 9.—SIMPLE GLASS PLATE MACHINE.

no accumulation of charges could result. To energize the action of the cushion its surface is covered with tin bisulphate, or an amalgam of zinc, tin, bismuth, and mercury. It is, however, not sufficient merely to produce a large quantity of electricity, but loss must be guarded against. In order to do so, the surrounding air must be kept as dry as possible, the plate and its support being well insulated and kept free from moisture, and a special provision, as shown in the accompanying illustration of Ramsden's machine of 1766 (Fig. 10), still further diminishes the loss from the plate. For this purpose sectors of silk are so fastened to the framework of the

machine that they cover, without touching, two quadrants of the disk, and thus oppose the loss through the air.

In figure 11 a cylinder machine is shown. Here the conductor carries the rubber that covers a part of the cylinder. If the one conductor is connected with the earth, the other will become raised to a higher potential and will be positive, so that the current will flow over the air gap from plus to minus. By reversing the connections with the earth the current may be reversed.

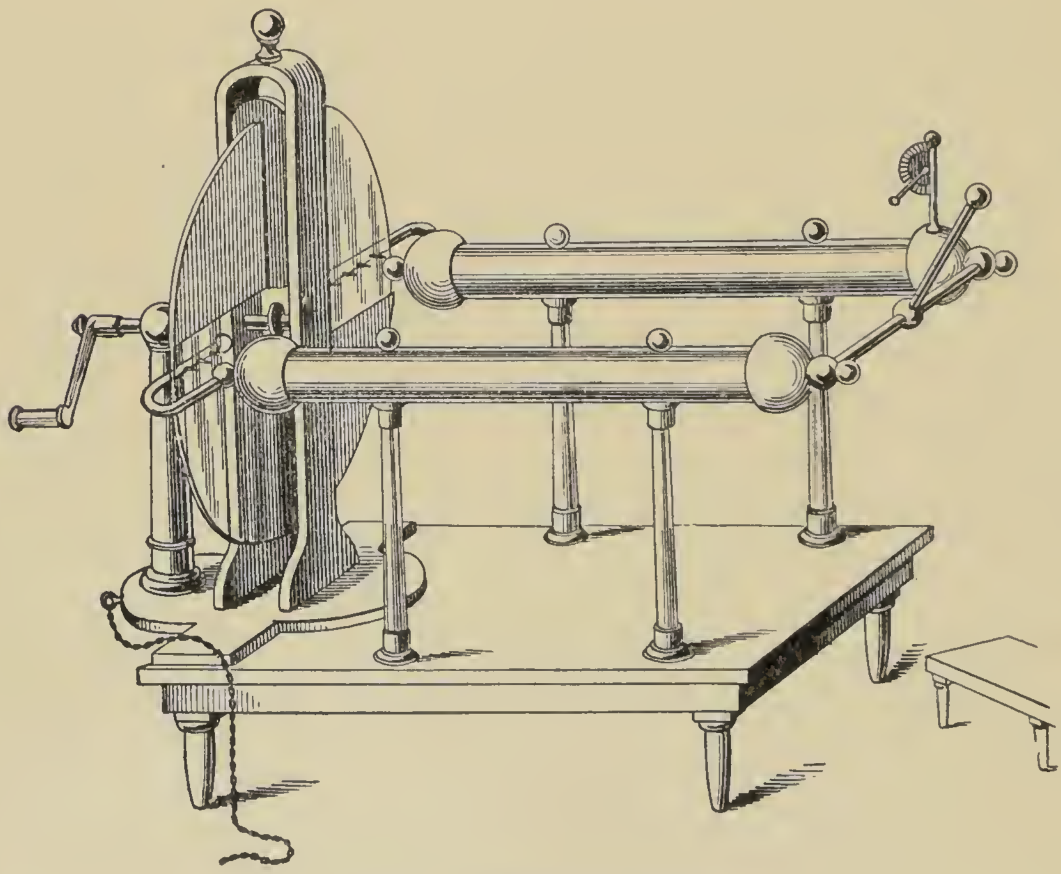

FIG. 10.—RAMSDEN'S MACHINE.

Before explaining the construction and action of another class of electric machines it will be necessary to describe the electrophorus, as these machines depend for their action not so much upon friction as upon influence.

The **electrophorus**, invented by Volta, is an apparatus for the repeated utilization of electricity during a longer time, after a single excitation, and consists of a cake of resin, hardened in a circular

metallic plate, and a cover, constituted by a disk of metal to which is attached an insulating handle of wood or glass.

In figure 12, A represents the shellac plate in its metal covering, D. B represents the metal plate with its insulating rod, C. In order to obtain charges we must first electrify the shellac plate by rubbing it with a piece of catskin. Then the plate is negatively charged. One gently places the metal disk B on the charged plate A, and grounds the upper surface of the disk by placing the finger on it ; on withdrawing the finger and removing the disk by means of the rod C, we shall find that the disk is positively charged with

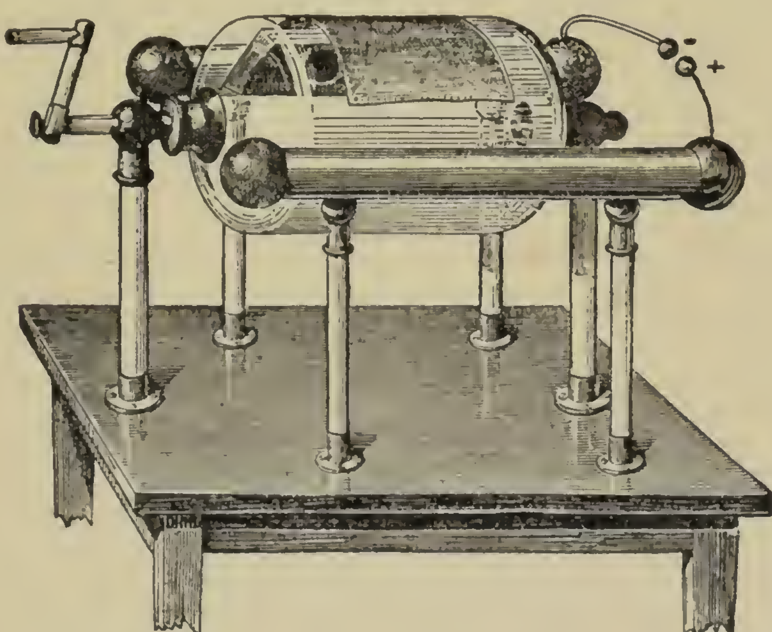

FIG. 11.—CYLINDER MACHINE.

electricity. This can be discharged and the experiment repeated with a like result. It is essential that the metal covering of the plate be in connection with the ground. If this condition is not observed, we shall find that very shortly we get no further charge.

The phenomenon of the electrophorus is dependent on the principle of induction, as explained on page 27. In order, however, to understand the mechanism, the plate A must be regarded as consisting of three parts instead of two. The shellac itself, although one and the same thing, acts like two—viz., the smooth surface is the charged body X, while the main portion of the shellac, A, acts

as an insulating substance, preventing the charge on X from neutralizing itself with the metal covering D. Therefore when the surface of the shellac is rubbed with catskin, we have the following condition in A: the surface X is negatively electrified, and by induction the metal covering D is positively electrified, because it is

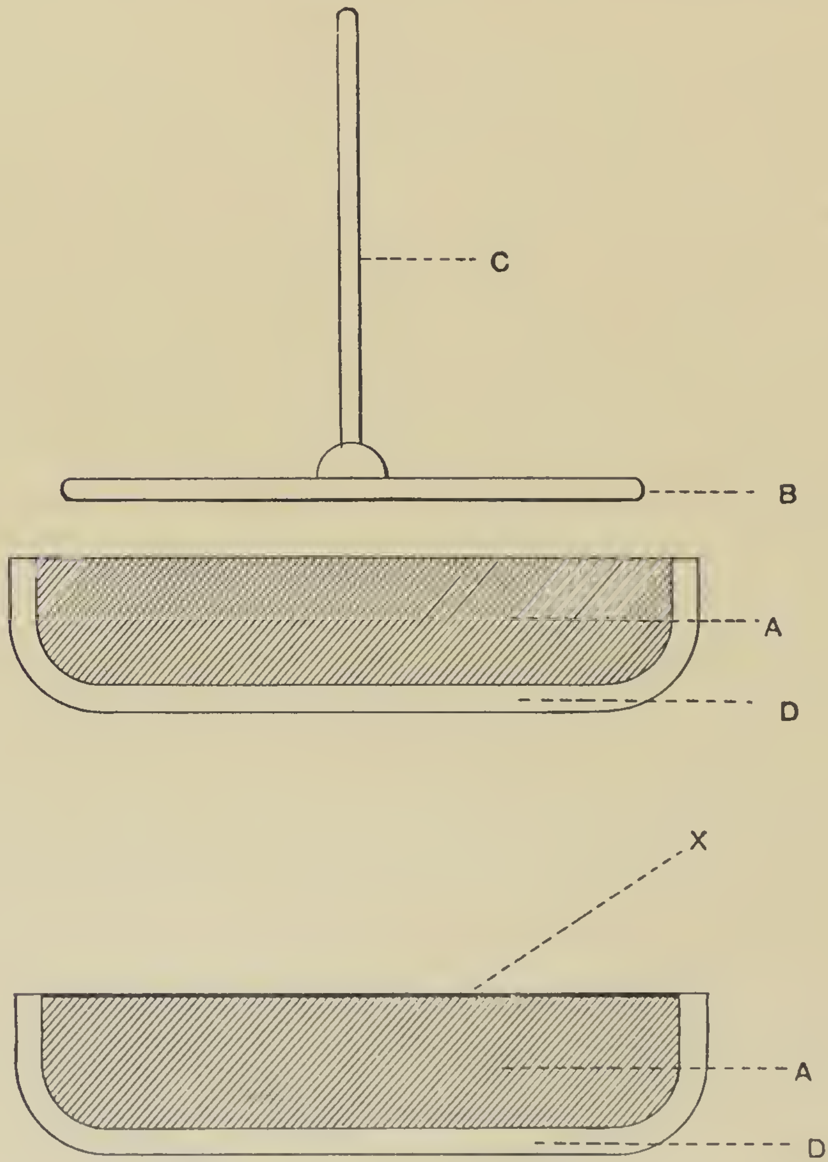

FIG. 12.—THE ELECTROPHORUS.

connected with the earth. The two charges are separated by the insulated shellac, which prevents a discharge, and thus they are held in their relative positions. In other words, the minus charge of the surface X influences the plus charge of D, and conversely

the charge on D tends to hold the charge on X. Now, when we place the disk B on X, there is a disturbance of the electric equilibrium of the disk. By induction its under surface becomes positively electrified and its upper surface becomes negatively electrified. By touching the upper surface with the finger we connect it with the ground, and thus allow the disk to regain its equilibrium in its new condition, by becoming completely and positively electrified. In this condition, then, we have the negative charge on X firmly held between two positive charges—viz., that on the disk and that

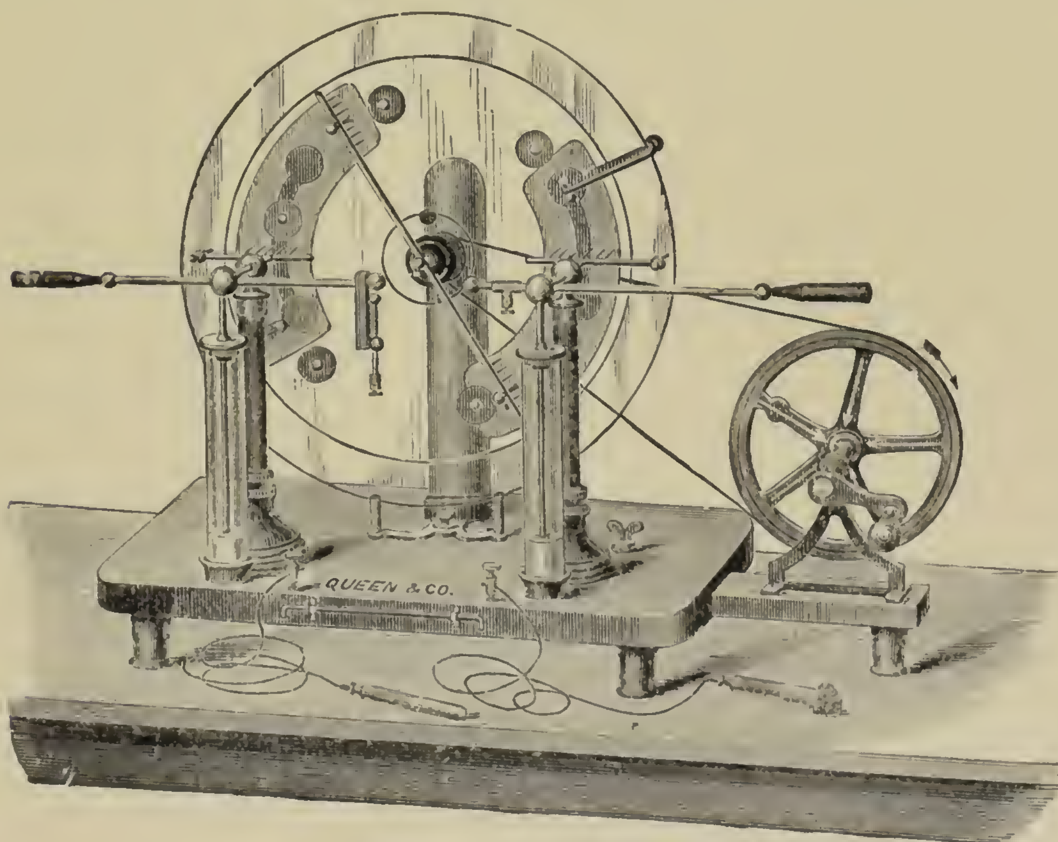

FIG. 13.—HOLTZ MACHINE.

on D; and this shows the importance of grounding D, as thus its positive charge constantly tends to hold the minus charge on X.

And now to return to the disk. On removing it from the shellac by means of the insulating handle it retains the positive charge it has acquired, and can be discharged at pleasure. After discharge the process can be repeated, and the same phenomena will take place in the same sequence.

The **influence machine** is in reality a form of revolving electrophorus. The earliest one of these is the Holtz machine (Fig. 13), which was invented in 1865. This machine consists of two varnished glass disks, one a little larger than the other, and placed three millimeters apart. The one is made to revolve, and the other remains stationary. The posterior stationary disk is insulated and contains two openings cut in at the opposite ends of any diameter. Upon the edges of these openings are pasted tongues of cardboard coated with shellac, the tongues pointing in the same direction as the axis of rotation; so that if one is directed downward, the other

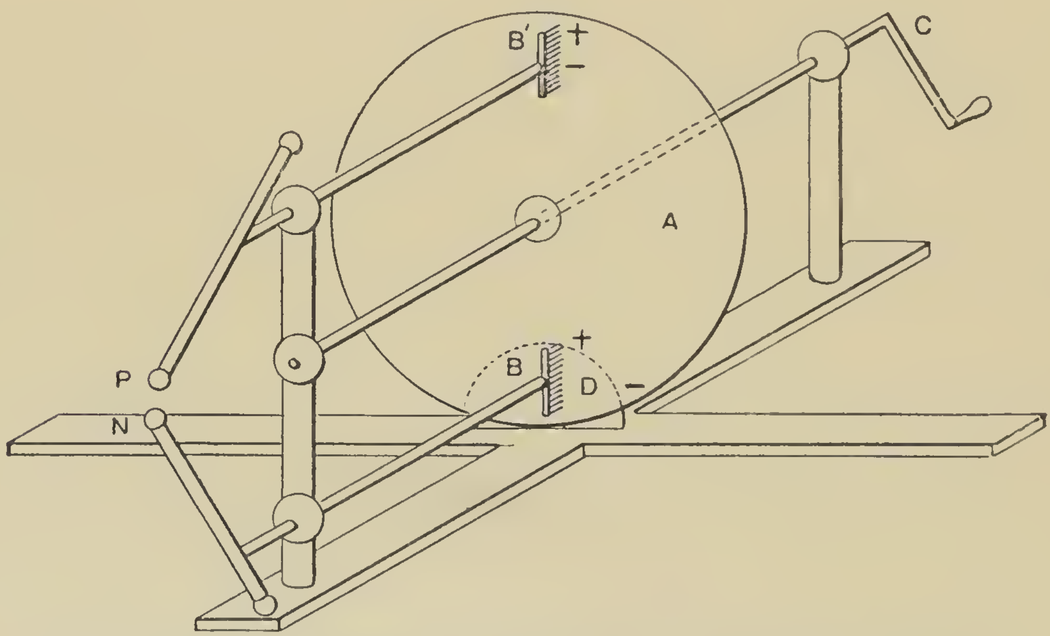

FIG. 14.—DIAGRAM SHOWING THE PRINCIPLE OF THE HOLTZ MACHINE.

is turned toward the upper part of the disk. These are called armatures, and serve the same purpose as the electrified surface in the electrophorus. In front of the anterior rotating plate, and opposite the windows of the stationary one, are two brass combs, connected respectively with a horizontal conductor that terminates in a knob and is carried by an insulating support.

In order to set the machine in action, the knobs of the conductors must be metallically joined; one of the armatures must first be electrified, by means of a piece of hard rubber, for instance, that itself has been previously electrified by friction; and the rotary

plate must be turned in a direction opposite to that indicated by the points of the armatures.

The working is complex, but by reference to figure 14 its principle will be made clear.

A is a revolving plate placed between D, a piece of hard rubber, corresponding to the armatures previously described, and a comb, B. Let the potential of D be reduced by rubbing it with catskin that is negatively electrified. By induction through the plate the comb B will become positive and the knob N negative. But the comb readily gives up its plus charge to the glass, so that the system B N is left negatively charged. When the glass disk has made half a revolution, that part that has been charged positively from the comb B arrives at comb B′. Thus the two conductors will always be at different potentials, and a steady flow of sparks passes between P and N. The simplest and most efficient of all induction machines is the Wimshurst (Fig. 15). It consists of two circular glass plates about one centimeter apart, mounted on a fixed horizontal spindle in such a way that they will rotate in opposite directions. Both disks are well varnished, and attached to the outer surface of each are narrow radial sections of tin-foil and metal buttons placed at regular intervals. Attached to the spindle on which the disks rotate is a bent conducting rod carrying at each of its ends a fine wire brush; these come in contact with the sections of foil or the metal buttons when the plates revolve. At the back is a similar bent rod placed at right angles to the one in front. Furthermore, two forks are provided with combs directed toward each other and toward the plates that rotate between them. The combs are supported on Leyden jars, to which are also attached the dischargers. The machine is entirely self-exciting and requires no friction or charging to start it. The initial charge is probably obtained from the atmospheric electricity. The presence of the brushes, buttons, and metal inductors is somewhat detrimental to the insulation of this machine, so that the energy produced is less than that given by a Holtz machine of the same size. The Wimshurst machine is especially trustworthy in charging and for creating a difference of potential, because a large amount of friction is developed between the metallic brushes and the metallic

sections or buttons on the plate. These sections or buttons are more numerous than those on the Toepler machine, and this, together with the fact that the plates are made to rotate in opposite directions, favors the rapid development of a charge.

The Toepler machine just mentioned is simply an elaborated modification of the Holtz.

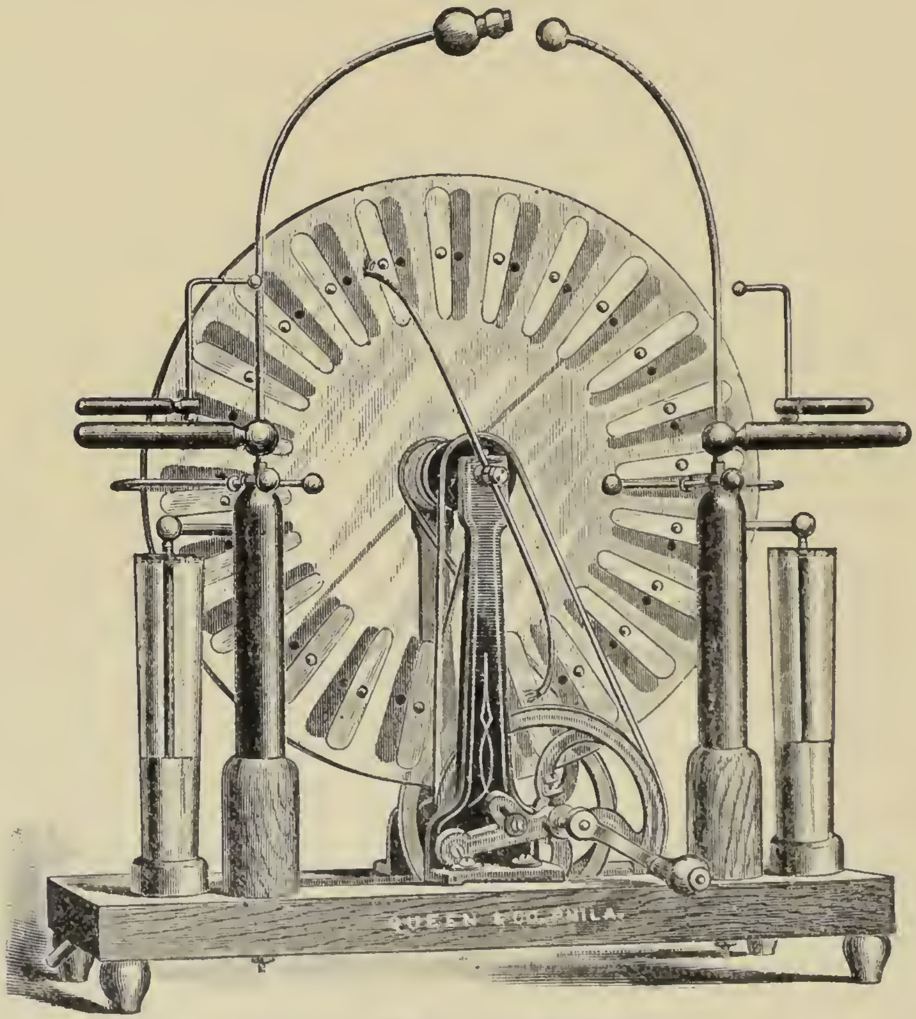

FIG. 15.—WIMSHURST MACHINE.

The power of these machines may be materially strengthened by suspending two condensers from the conductors.

Materials other than glass have been used for the plates in the static machines, and various claims are made for them. Among these, the mica-plate machine may be mentioned; in this the revolving plates are made of mica, while the stationary plates are of glass. It is claimed for these machines that they do not lose their

charge so readily, because mica does not collect moisture, and that the polarity of the machine remains constant.

The **condenser** is an apparatus for storing up a large amount of electricity upon a small surface. It consists in all cases of two insulated conductors separated by a nonconductor, and acts by induction. A simple condenser is made of two metal plates: a lower one that rests with its under surface upon an insulating glass foot and has its upper surface covered with a thin coating of insulating shellac; and an upper plate to whose upper surface an insulating handle is attached (Fig. 16). If the upper plate is now placed upon the lower one and the latter is touched by a positively electrified body, while a connection is established between the upper one and the earth, the lower plate will take a certain positive charge. According to the principles already explained, the upper plate will become negative, and, by attracting the plus potential of the lower plate, will not allow this to become free, but keeps it fixed—*i. e.*, free from tension. As a result of this the lower plate will be able to absorb more electricity from its source, and this again will cause a further accumulation of negative electricity on the upper plate. Thus it will be seen that the capacity of the lower plate will be increased, and that of the upper plate will also be correspondingly enlarged, but will, of course, possess the opposite potential. If the connection between the upper plate and the earth be broken and this plate be lifted by its insulating handle from the lower one, the electricity contained in the latter will no longer be held down, but will become free and may be discharged at will. Condensers of modified form are shown in figures 17 and 18.

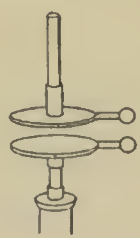

Fig. 16.—Metal Plate Condenser.

Upon the same principle as the condenser is based the Franklin plate.

The **Franklin plate, or fulminating pane,** consists of a glass plate partially covered on both sides by tin-foil; a broad border on both sides of the plate remains free from foil and is varnished with shellac. The anterior surface of the plate (corresponding to the lower surface of the condenser) is connected with the conductor of

an electric machine; the posterior surface (corresponding to the upper or collector plate of the condenser) is placed in connection with the earth. The charging of the two surfaces is carried out in

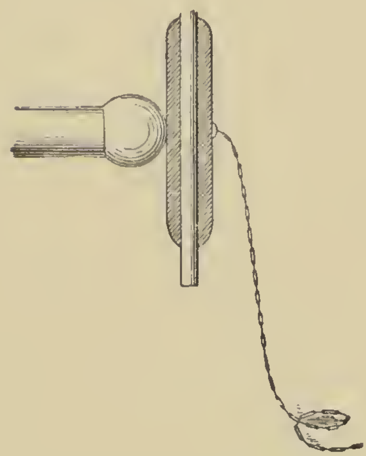

FIG. 17.—CONDENSER.

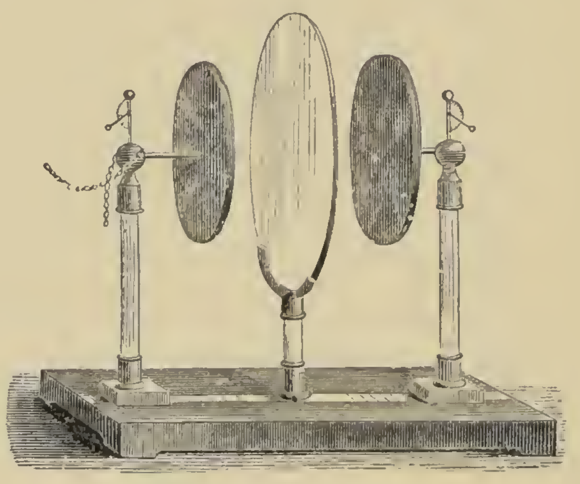

FIG. 18.—CONDENSER.

the manner described for charging the condenser. Such a fulminating pane, rolled up, constitutes a Leyden or Kleist jar (Fig. 19).

The **Leyden jar** is most conveniently made of a glass bottle of suitable size, coated on its inner and outer surfaces for about two-thirds of its height with tin-foil. The uncovered surface is coated with an insulating varnish; the mouth of the bottle is closed by an insulated cork; through this cork passes a metal rod, ending externally in a knob and internally being in communication with the tin-foil. When, now, the metal knob is connected with the conductor of an electric machine and the outer covering of tin-foil is connected with the earth, this apparatus may be charged in the same manner as the two preceding ones.

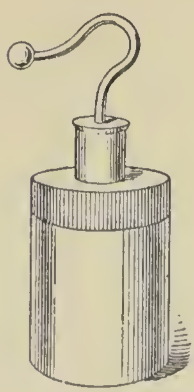

FIG. 19.—LEYDEN OR KLEIST JAR.

It is discharged explosively by forming a connection between the two coverings. It may thus safely be grasped by either alone, but if carelessly handled, may give the operator a severe shock. All actions of the electric machines may, by means of such bottles, be materially increased.

CHAPTER III

DYNAMIC ELECTRICITY

Chemical Generators. Galvanism. Voltaic Pile. Current. Circuit. Cells. Elements. Electrolyte. Various Forms of Cells. Battery. Positive and Negative Plates. Poles. Current Direction. Pressure. Resistance. Ohm's Law. Arrangement of Cells.

Electricity in equilibrium, which we have just studied, is known as **static electricity**; electricity in motion is known as **dynamic electricity.** Any two substances placed in contact, or in a liquid, will show a difference in potential; but only a few, especially the metals and carbon, will show enough difference to be appreciable by indicating instruments.

Even the greatest differences of potential thus obtained are smaller than those produced by friction, and the pith-ball apparatus would not be affected by them. By more delicate instruments these differences can be recognized. Such an electrometer of most sensitive character is called Thompson's quadrant electrometer, and consists of a light rod or needle of metal, suspended horizontally by a fine wire over four pieces of brass forming the four quadrants of a circle. The opposite quadrants are connected by wires, and the adjacent ones are insulated from each other. All four are insulated from the rest of the instrument, and the whole is covered by a glass shade. The suspended rod is kept at a high positive potential by an arrangement the principle of which it is not necessary to enter upon here. A small mirror that reflects upon a screen a ray of light from a lamp is attached to the rod; hereby the smallest movement of the needle becomes visible upon the screen. By means of such an instrument we can observe that differences of potential are manifested upon mere contact of heterogeneous substances. It was to such contact alone that Volta assumed the phenomena produced by the pile that bears his name to be due. It will, however, be seen that the current of the voltaic pile is probably due to chemical

action. This pile is formed by the superposition of a certain number of couples. Each couple is composed of a disk of copper, C, and a disk of zinc, Z, separated by a disk of cloth that is saturated with acidulated water (Fig. 20). Each one of these couples may be surrounded by glass, the quantity of fluid increased, and we have a galvanic or voltaic cell. Thus a cell will be constituted

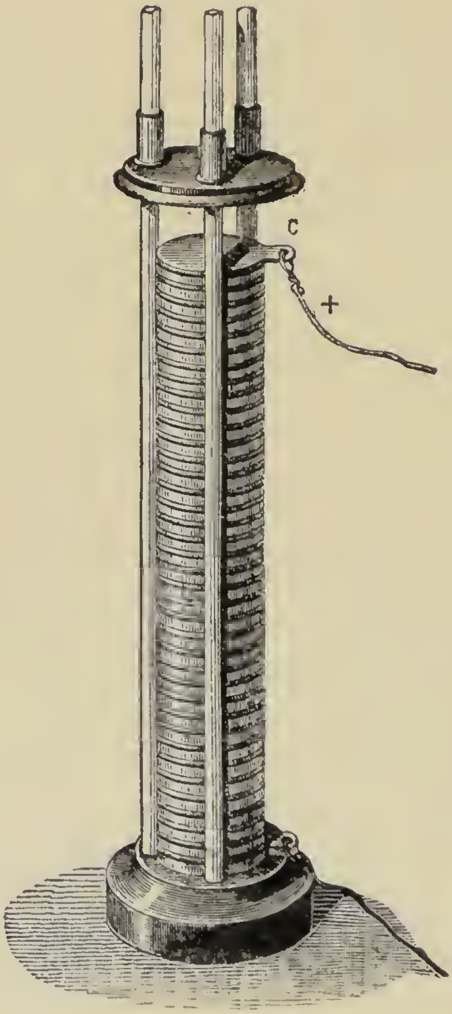

FIG. 20.—VOLTAIC PILE.

essentially by an isolating jar containing a fluid, in which two plates of different metal are immersed. The contact or chemical action that here occurs produces a difference of potential, which sets in motion an electromotive force. Every cell is characterized absolutely by the electromotive force that it possesses, and by the conductivity, or conversely the resistance, that it presents to this force.

If the free ends of the two metals that are immersed in the fluid are connected by a conductor of electricity,—for instance, a copper wire, —the various potentials begin to equalize themselves in the closed circuit, consisting of metal 1, fluid, metal 2, and copper wire, as shown in figure 21 ; and inasmuch as the constant contact of the metals with the fluid produces an accumulation of electric energy that is constantly being renewed, the equalization of potentials will not only be momentary, but will be kept up constantly. This equalization of potentials in the connecting wire we call the **electric current**, and the all-round path is called a **circuit.**

We have already spoken of current in the chapter on Frictional Electricity, but there we were always dealing with momentary currents. No matter how rapidly spark follows upon spark or discharge follows upon discharge, there is always an appreciable gap between them, due to a pause in the collection of electricity from its source. In contradistinction thereto, the current that is produced by the voltaic cell is a constant one, and the current derived from such a cell is also known as the constant or galvanic current. The latter name has been generally adopted by medical writers in honor of Galvani.

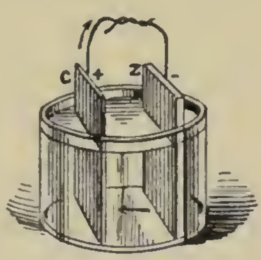

FIG. 21.—SIMPLEST FORM OF CELL.

All voltaic cells may be divided into two general classes : (1) The single-fluid cells, or those that have but one exciting fluid. (2) The double-fluid cells, or those that have two exciting fluids.

Every voltaic cell consists of two essential parts : (1) A voltaic pair, or voltaic couple. (2) One or two exciting fluids.

The two substances forming the voltaic couple are called the elements ; the fluid is called the electrolyte of a cell. The elements, which generally consist of two dissimilar metals, although they may be formed of a variety of substances, are known as the positive and negative plates, the positive plate always being the one that is most attacked or acted upon by the electrolyte. If such a couple, say one of copper and zinc, be immersed in dilute sulphuric acid, so far as can be seen no change takes place, although the maximum electromotive force of the couple must be

set up. As soon, however, as the plates are joined externally by a conductor, bubbles of hydrogen will be seen to form at the copper plate.

These bubbles set up a counter electromotive force, known as polarization, and also reduce the conductivity of the cells—that is to say, increase the internal resistance. As a result of both of these processes the capability of the cell to furnish current is diminished.

The bad effects of polarization may be overcome in a variety of ways :

1. Mechanically, by loosening the bubbles from the plate to which they adhere—that is, by brushing them away or by agitating the liquid.

2. Chemically, by surrounding the plate upon which the bubbles of hydrogen form, by some powerful oxidant, one that will oxidize the hydrogen without having an injurious effect upon the cell ; or by making use of the hydrogen for some chemical decomposition, which, however, must also be innocuous to the cell itself.

The first method is rather impracticable, and therefore it is the second method that is satisfactorily made use of in various kinds of cells.

As the voltaic cell is an important source of electromotive force as employed in therapeutics, we shall briefly describe some of the most practical forms.

Cells.—One of the first successful attempts at modifying the evils of polarization was made in 1836 by Professor Daniell.

The Daniell cell (Fig. 22) consists of an outer glass jar, G, containing a split cylinder of zinc, Z, inside of which is a porous jar, P, of unglazed earthenware, and inside of this a copper cylinder, C, at the top of which is a perforated ledge, upon which are placed crystals of cupric sulphate, or blue stone. The outer zinc cylinder is immersed in dilute sulphuric acid ; the inner copper cylinder, in a solution of cupric sulphate. The crystals of cupric sulphate upon the ledge of the cylinder keep the solution in a state of saturation.

As soon as the cell is placed in action, the zinc and copper plates being joined externally by a conductor, the zinc is attacked

by the sulphuric acid, the hydrogen of the latter is set free, and zinc sulphate is formed. The freed hydrogen passes through the porous jar and comes into contact with the copper sulphate ; here it takes the place of the copper, leaving this free and forming sulphuric acid. The freed copper from the copper sulphate solution becomes fixed upon the copper plate, thus always giving a clean copper surface.

Thus the copper sulphate is employed to take up the objectionable hydrogen, and a cell is thereby obtained with little or no polarization. Its electromotive force, however, is small, and its internal resistance is large.

This Daniell cell has been variously modified in order to effect a

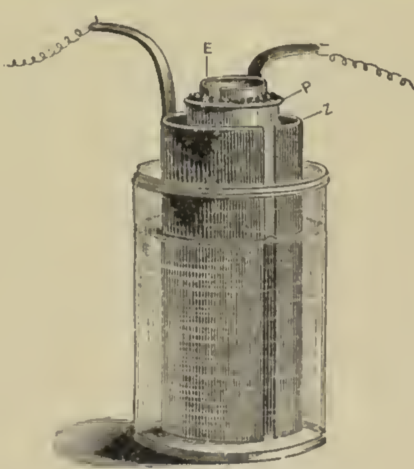

FIG. 22.—DANIELL CELL.

diminution of the internal resistance ; thus the porous jar has been eliminated, and solutions of different density—copper sulphate and zinc sulphate—surround the horizontally placed elements of the cell ; as the specific gravity of the copper sulphate solution is greater than that of the zinc sulphate, the former is placed at the bottom of the vessel, while upon it, but of course not mixing with it, is poured the solution of zinc sulphate.

Such cells are also often called gravity cells (Figs. 23 and 24).

Grove Cell.—In the cell invented by Grove and known by his name the hydrogen is gotten rid of, and at the same time a higher electromotive force is obtained, by surrounding the copper

element, or its substitute, with a strong oxidizing agent. In the Grove cell the copper of the Daniell cell is replaced by platinum, and the copper sulphate by nitric acid.

Thus this cell consists of zinc in dilute sulphuric acid outside of

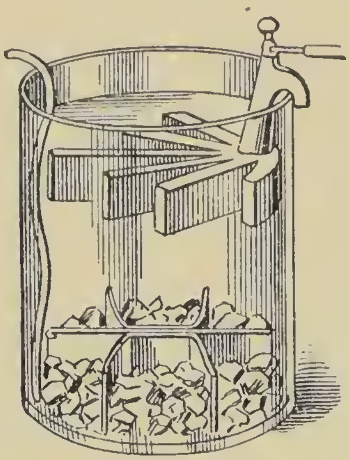

FIG. 23.—GRAVITY CELL.

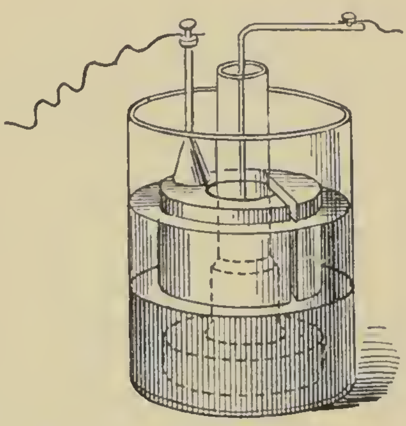

FIG. 24.—GRAVITY CELL.

the porous jar, and platinum in nitric acid inside the porous jar. When the cell is in action, the zinc is attacked and zinc sulphate formed, as in the Daniell cell; the free hydrogen coming into contact with the nitric acid takes oxygen from it and forms water,

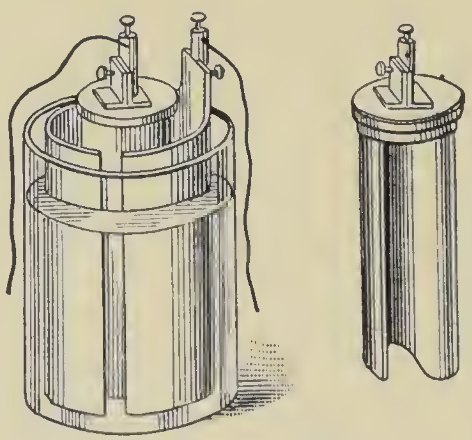

FIG. 25.—GROVE CELL.

leaving, however, another compound of nitrogen and oxygen, which is given off in poisonous red fumes, so that this battery cannot be utilized unless some means is employed for carrying off these fumes. Although polarization is effectually prevented in this cell,

the nitric acid soon becomes very weak and the sulphuric acid is soon replaced by zinc sulphate. The electromotive force, which in the beginning is large, rapidly decreases. The Grove cell is shown in figure 25.

Bunsen Cell.—On account of the high cost of platinum, Bunsen suggested the use of hard gas-coke or carbon as a substitute, and this modification is known as the Bunsen cell (Fig. 26).

While the electromotive force of the Bunsen cell is about the same as that of the Grove, its internal resistance is higher, but its current lasts longer.

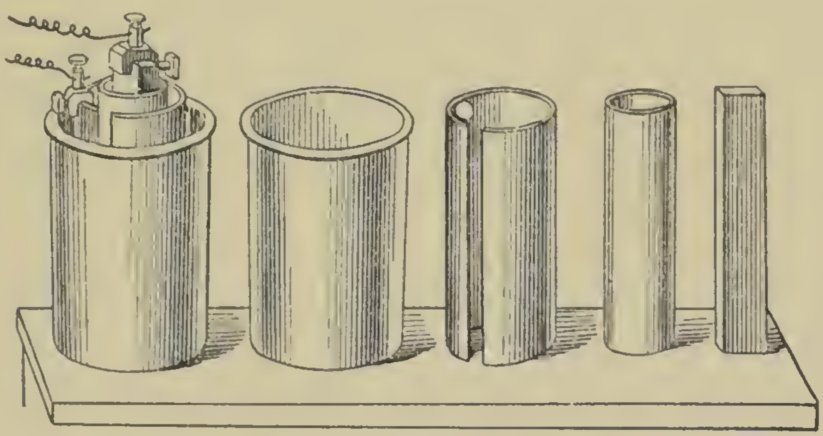

FIG. 26.—BUNSEN CELL AND ITS COMPONENT PARTS.

Single-fluid Cells.

For simplicity in construction, cells employing a single exciting fluid, simple or compound, have been devised.

Zinc-platinum Cell.—This cell, known as Smee's, consists of a plate of zinc and a plate of platinized silver, dipping in dilute sulphuric acid. The electromotive force is low.

Zinc-carbon Cell.—This consists of a pair of zinc and carbon plates, dipping into a weak solution of sulphuric acid (1 : 10 or 20 of water). The electromotive force is somewhat higher than that of Smee's cell.

Bichromate or Chromic Acid Cells.—In order to do away with the objectionable fumes arising from the use of nitric acid as an oxidant, chromic acid and potassium bichromate have been largely used in substitution. There are many forms of these cells.

Grenet Cell.—Such a cell, one largely used for medical purposes, is the Grenet. This consists of a glass flask, into which reach, from a cover of hard rubber, two carbon plates and an adjustable zinc plate attached to a long brass rod (Fig. 27).

The carbon plates reach to the bottom of the vessel, while the zinc plate may be pressed down into the lower half of the vessel that contains the fluid, or may be drawn to the upper part, so that it does not come in contact with the fluid at all. By this means the cell is easily put into and out of action.

Amalgamation.—In all zinc-carbon cells the zinc is chemically attacked by the acid of the electrolyte. When impure zinc is used,

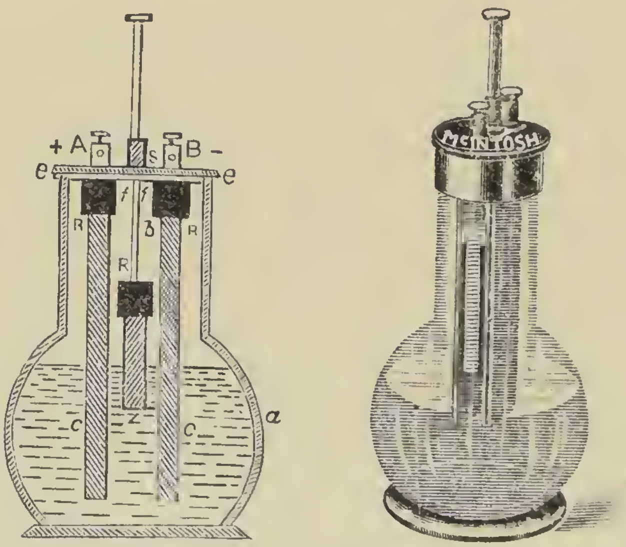

Fig. 27.—Grenet Cell.

as is usually the case on account of the difficulty of obtaining pure zinc (the ordinary zinc of commerce contains more or less iron or lead, and these metals are electronegative to zinc), a series of elements is formed between the impurities of the zinc and the zinc itself. These minute couples of elements when attacked by the electrolyte form complete circuits. The action of these couples is called local action, and the electric energy thus generated cannot be utilized. It has been found that such local action can be avoided by rubbing the clean zinc plate with mercury. When mercury is rubbed over the plate, it dissolves the zinc and forms a coating of zinc amalgam on the plate. The impurities are not dissolved, so

that it is only the zinc amalgam that comes in contact with the acid. As fast as the zinc of the amalgam is acted upon by the acid, just so fast does the mercury dissolve fresh zinc from the plate.

The electromotive force of this cell is high, but its constancy is not great.

A good solution for such a cell is as follows :

	Grams.
Potassium bichromate,	15
Sulphuric acid,	15
Water,	250
Mercury oxysulphate,	5

The use of the mercury oxysulphate is for the amalgamation of the zinc.

Instead of the foregoing fluid, electropoion fluid may be used. This is made by adding two parts of sulphuric acid to eight parts of water, and while the mixture is still hot stirring in one part, by weight, of pulverized potassium bichromate. As soon as it is cold it is ready for use. An earthen vessel should be used for mixing. When this fluid is used, the zinc must be amalgamated more frequently. This may be done in the following way : Mix 250 grams of nitric acid with 500 grams of hydrochloric acid, and then slowly add 125 grams of mercury ; when dissolved, add 700 grams more of hydrochloric acid, and stir well. Cleanse the zinc with potash, and dip it into the foregoing solution for several seconds. Rinse in clear water and rub with a stiff brush. The amalgamation may be effected in a simpler manner by first dipping the zincs into dilute sulphuric acid to cleanse them, then dipping them into a vessel of mercury, and finally allowing the surplus to drain off.

Leclanché Cell.—The Leclanché cell is a zinc-carbon couple with an electrolyte of ammonium chlorid (sal ammoniac), and with manganese peroxid as a depolarizer. The action depends on the ammonium chlorid giving up free ammonia and forming zinc chlorid. Other chemical actions also take place. Finally hydrogen is liberated, which comes in contact with the manganese peroxid and reduces it to a lower oxid.

Manganese peroxid parts with its oxygen comparatively slowly, so that if hydrogen is produced too rapidly,—and this is the case

when the cell is working,—only a part of it is neutralized. If, however, the cell is used only for a short time and then allowed to rest, the hydrogen is gradually neutralized and the cell soon recovers its normal state. These cells are admirably adapted for medical work, require very little attention, last for a long time when properly used, and are easily renewed.

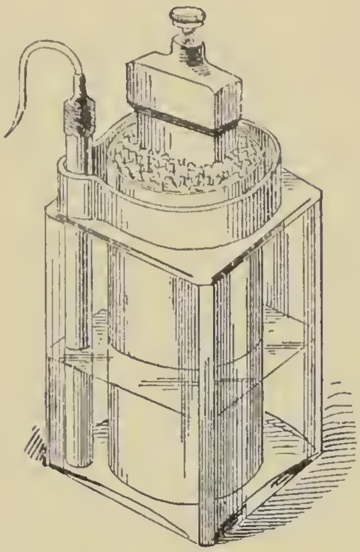

Fig. 28. — Original Leclanché Cell.

In the original form this cell contained a porous jar filled with the depolarizing material, in the center of which was placed the carbon plate (Fig. 28). As the sole office of the porous jar was to keep the material together, Leclanché abandoned it, and accomplished its purpose by compressing a mixture of carbon, manganese peroxid, gum, and a small quantity of potassium bisulphate into a hard mass, after keeping the mixture for some time at the temperature of boiling water. Plates of this compressed material are fastened, one at each side

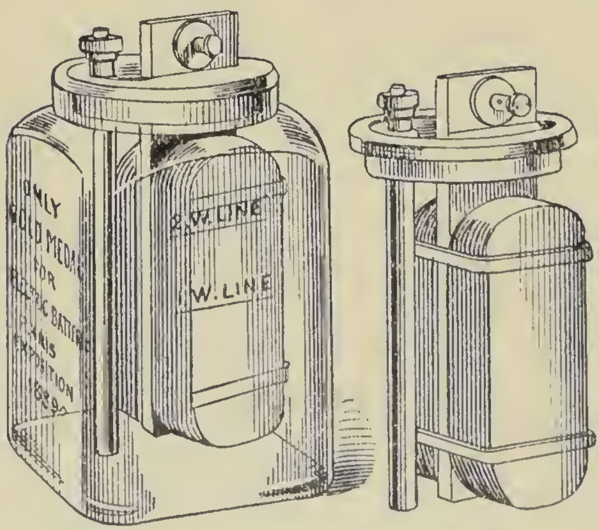

Fig. 29.—Leclanché Cell Without Porous Cup.

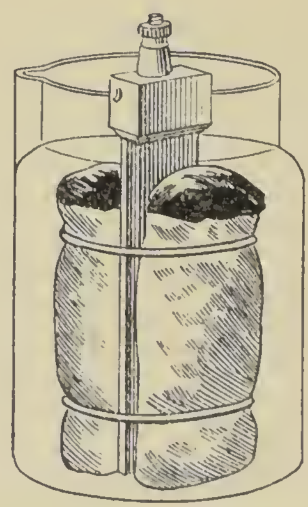

Fig. 30.—Modified Leclanché Cell.

of the carbon element, by means of rubber bands. The internal resistance of these cells is lower than that of those containing the porous cups (Fig. 29).

A practical modification of this form of cell is shown in figure 30.

Here the depolarizing mixture is contained in two bags, which are tied on the opposite sides of the carbon elements, thus allowing free circulation of the solution.

Another very practical modification of the Leclanché cell is the Law telephone cell, shown in figure 31.

The **silver chlorid cell** consists of a zinc-silver couple, immersed in a dilute aqueous solution of sal ammoniac and sodium chlorid. As made by Gaiffe, it consists of a plate of zinc, Z (Fig. 32), and a plate of silver chlorid, Y, fused around a wire and envel-

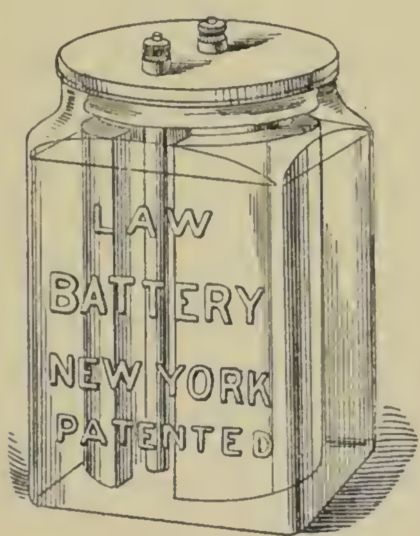

FIG. 31.—LAW TELEPHONE CELL.

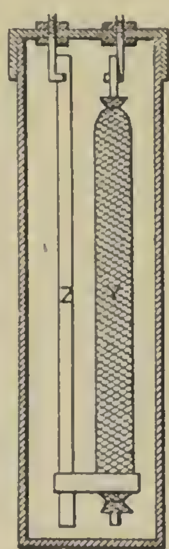

FIG. 32.—SILVER CHLORID CELL.

oped in a cotton bag, the whole contained in a vessel of hard rubber hermetically sealed by a cork, to the top of which are attached the binding posts for making connections. A cushion composed of six or eight sheets of blotting-paper fills the space between the two elements, keeps them apart, and is saturated with the exciting fluid.

Dry cells, so called, are not really dry, and their name is badly chosen, since their action is dependent upon the presence of a liquid electrolyte. The liquid used is, however, made into a paste with some gelatinous substance or powdered material; in so far as they contain no free liquid, they may be considered dry.

Batteries.

When, now, we properly connect a number of cells, of whatsoever construction, we have a **battery.** The chemical action upon one of the plates of the cell must be greater than upon the other in order to produce a difference of potential, and the plate that is most attacked is called the active or p o s i t i v e p l a t e ; the other is the inert or n e g a t i v e p l a t e. As electricity always flows from a point of higher potential toward one of lower potential, the direction in the liquid will be from the plate most attacked—*e. g.*, in a zinc-carbon cell,

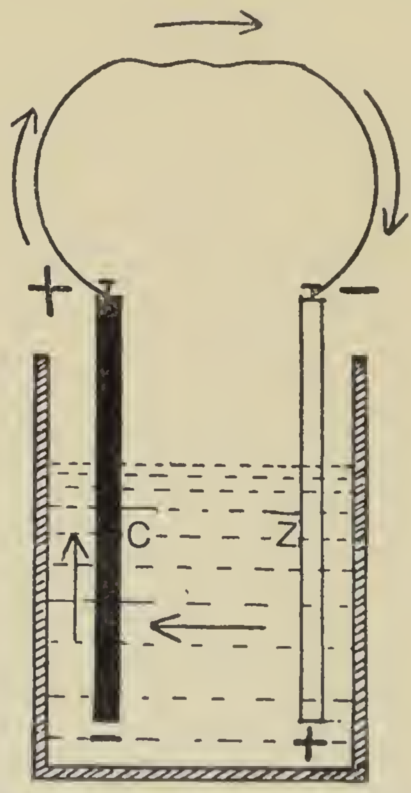

FIG. 33.—SHOWING THE FLOW OF CURRENT FROM POSITIVE TO NEGATIVE PLATE, AND FROM POSITIVE TO NEGATIVE POLE.

from the zinc to the carbon—from the positive to the negative plate. If to each plate or element a conducting wire be attached, the current will spread through each such wire, and inasmuch as the higher potential of the zinc forces the current to the carbon, and through the carbon into the conducting wire, the wire attached to the carbon will be found to be of higher potential than is that attached to the zinc. The terminal of the plate that is out of the fluid, or the end of the conductor attached to this terminal, is called the p o l e or e l e c t r o d e.

It will thus be apparent that the negative plate of the cell will carry the positive pole; and that therefore outside of the cell the current flowing from the positive to the negative pole will flow from the negative to the positive plate. Whatever misunderstanding may arise in regard to this must be due to the fact that the terms plate and pole are not clearly differentiated. The accompanying illustration (Fig. 33) will render this clear.

We should always remember that in speaking of current we refer to a flow from a higher to a lower level. Any substance that is of a higher potential than another with which it is placed in connection, by whatsoever medium, will be electropositive, while the other would be electronegative. Such a list of substances, placing the bodies of higher potential first, is called an electromotive series. Of course, the current in the wire externally connected will proceed from the body lower in the list to a higher one. Such a list is the following:

Zinc	Nickel	Copper
Cadmium	Bismuth	Silver
Tin	Antimony	Gold
Lead		Platinum
Iron		Graphite.

From this it will be seen that if the elements of a cell are constituted of zinc and copper, the current in the wire will flow from the copper to the zinc, while in a copper-graphite combination the flow will be from the graphite to the copper.

Pressure.

In order to gain a clearer insight into **electromotive force** and the laws that govern it, let us call it pressure, and compare it with the pressure of water.

Let us take a glass jar filled with water and connected to a glass tube by means of a piece of rubber tubing, and place the entire apparatus on a table. If we lift the jar of water from the table, the glass tube remaining stationary, the water-level in the glass tube will at once rise until it has attained the level of the water in the jar. The higher we raise the jar, the higher will rise the water in the tube (Fig. 34). Thus the pressure of the water is proportional

to the difference of level ; increasing this difference increases the pressure ; decreasing it decreases the pressure.

The difference of electric potential is the cause of electric pressure, and here also the pressure is proportional to the difference of potential, and by increasing or decreasing the latter we increase or decrease the former.

Resistance.—The opposition that the path of a current furnishes to its flow can best be understood by like comparison with the flow of water. Thus, if in a cistern of water the pressure be kept constant by a continuous inflow, and water be allowed to escape from a

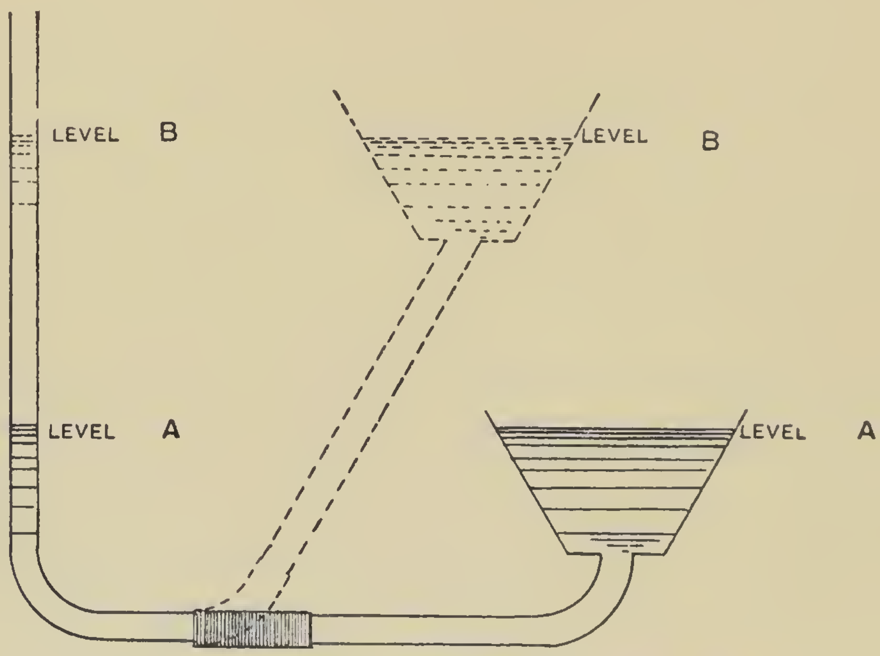

FIG. 34.—SHOWING VARIATIONS IN WATER PRESSURE.

pipe of a certain area at the bottom of the cistern, then a certain quantity of water will escape in a given time. If the area of this escape pipe be made smaller, the water of the outflow will be correspondingly diminished. If the area of such a pipe be doubled, or, what is the same, if two such escape pipes be furnished, the rate of the outflow will also be doubled. The rate of flow can also be increased or diminished by largely increasing or decreasing the length of the pipe, for its walls offer some resistance to the flow of water, and thus an increase in length would increase the resistance, and through this oppose the flow, while the decrease would

diminish the resistance and facilitate the flow. Therefore the flow of water under constant pressure would be directly proportional to the area or caliber of the pipe, while it is inversely proportional to the length of the pipe. These principles govern the flow of electricity also.

As already stated, electric conduction is the reverse of resistance, so that a good conductor offers slight resistance to the flow of the current. The metals, being good conductors of electricity, offer least resistance to its flow. The following table of conductors may therefore be used in inverse order as a table of resistances, the good conductors being bodies of slight resistance, the semiconductors being bodies of great resistance, and the insulators being bodies of so great resistance that they almost effectually oppose the passage of any current.

TABLE OF CONDUCTORS AND RESISTANCES.

Good Conductors.	Semiconductors.	Insulators.
Silver.	Carbon.	Wool.
Copper.	Graphite.	Silk.
Gold.	Acids.	Sealing-wax.
Aluminum.	Saline solutions.	Sulphur.
Zinc.	Sea-water.	Resin.
Platinum.	Melting ice.	Gutta-percha.
Iron.	Pure water.	India-rubber.
Tin.	Stone.	Shellac.
Lead.	Dry ice.	Paraffin.
German silver.	Dry wood.	Vulcanite.
Antimony.	Porcelain.	Glass.
Mercury.	Dry paper.	Dry air.
(*Slight Resistance.*)	(*High Resistance.*)	(*Very High Resistance.*)

Usually copper wire is employed for electric conductors.

If we examine the circuit of an electric current, we see that it consists of a cell and of the connecting wire, so that the resistance of the entire circuit will include the resistance of the metals and the liquid of the cell and of the wire, as well as of every other conductor that may join the poles of the cell. The resistance of the cell itself is called the internal resistance of the circuit; that of the other parts, the external resistance. The former is symbolized by "r," the latter by "R."

The Electric Circuit.—If, now, instead of the cistern of water we make use of an electric apparatus for the production of pressure, and connect one side of the apparatus with the other so as to establish a continuous path, we shall find that the same laws apply, and we shall learn more regarding the laws that govern the flow in a circuit. In order to have some indication of the flow of current, we place in the external circuit a galvanometer. The galvanometer is an instrument that, by the deflection of its needle, shows the strength of an electric current passing through it ; the principle and construction of such an instrument will be discussed later.

Thus, in figure 35 the external circuit is made up of three wires,

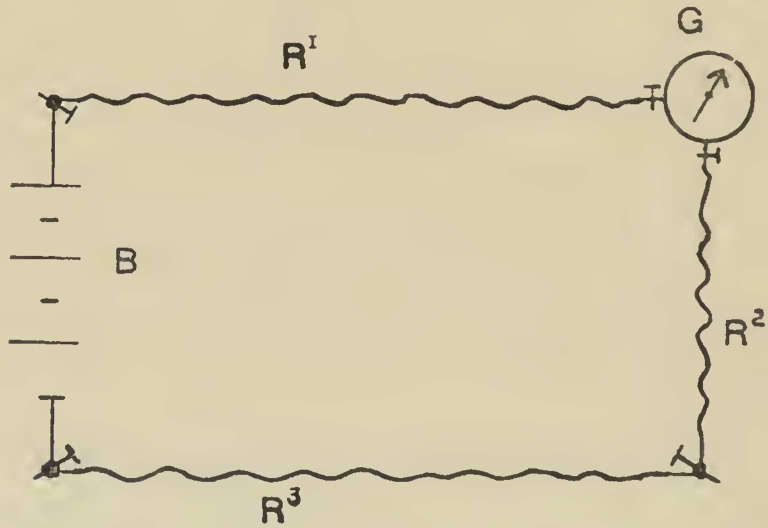

Fig. 35.—Showing a Simple Circuit Containing Three Equal Resistance Wires.

each being of the same length and caliber, thus giving the same opposition to the flow of current. Into the circuit is also introduced a galvanometer, G. The needle of the galvanometer swings to a certain point. If one of the wires be removed, the needle comes back to the point of rest that it occupied before its introduction into the circuit, thus showing that no current flows unless the path is continuous. If the wire 1, 2, or 3, be removed and replaced by another of equal length but of larger cross-section, the needle will be deflected to a greater extent than in the first experiment, showing that more current passes in consequence of the increased diameter of the new wire, and that it does not matter where the circuit

is altered, the deflection always being the same. If two wires be replaced by thicker ones, the needle will be still further deflected, and still more so if all three wires be changed. Such a circuit, made up of one continuous path, is said to be a **simple circuit**;

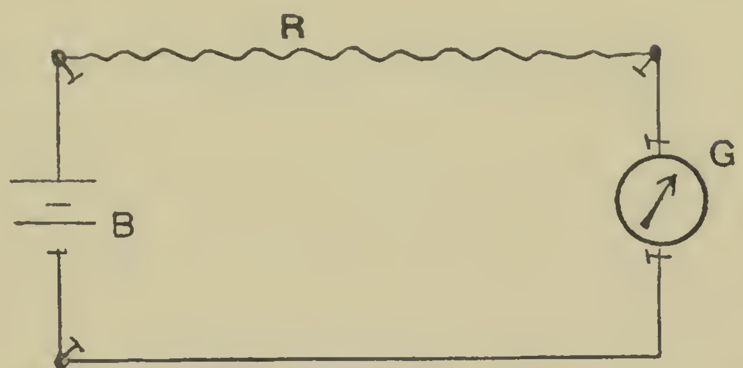

FIG. 36.—SHOWING A SIMPLE CIRCUIT CONTAINING ONE RESISTANCE WIRE.

when the circuit consists of two or more branches, it is said to be a **divided circuit.**

If we make a circuit with one resistance coil interposed and note the deflection of the galvanometer needle (Fig. 36), and then join to this resistance coil another of the same length and thickness of wire (Fig. 37), the resistance having been doubled, the deflection

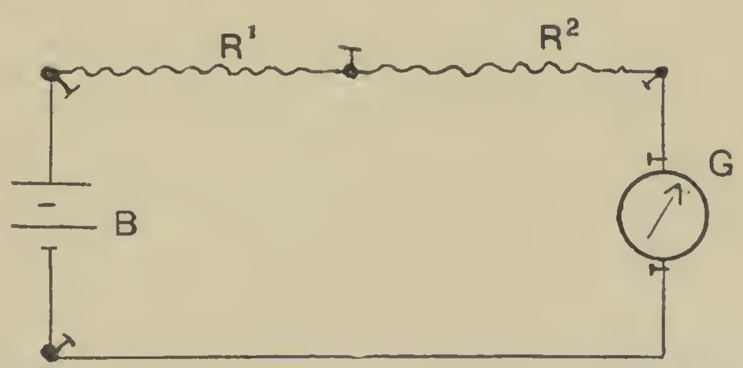

FIG. 37.—SHOWING A SIMPLE CIRCUIT CONTAINING TWO RESISTANCE WIRES IN SERIES.

will be one-half of what it was before; but if, instead of joining the wires end to end or in series we place them side by side, as in figure 38, the deflection will be doubled, for here we have, by putting the wires side by side in parallel, doubled the thickness without changing the length.

Thus, increasing the length of the wire increases its resistance, and increasing its thickness decreases its resistance, as we shall show later. Inasmuch as the deflection of the galvanometer needle is proportional to the current that influences it, we may say that current varies inversely as resistance.

If, furthermore, in any of the foregoing experiments we leave everything unaltered except the electric apparatus, but substitute for this one of double the electromotive force, we shall in each case obtain double the deflection—*i. e.*, twice the current; which shows that the current varies directly as pressure or electromotive force.

Professor Ohm proved not only that with constant currents the

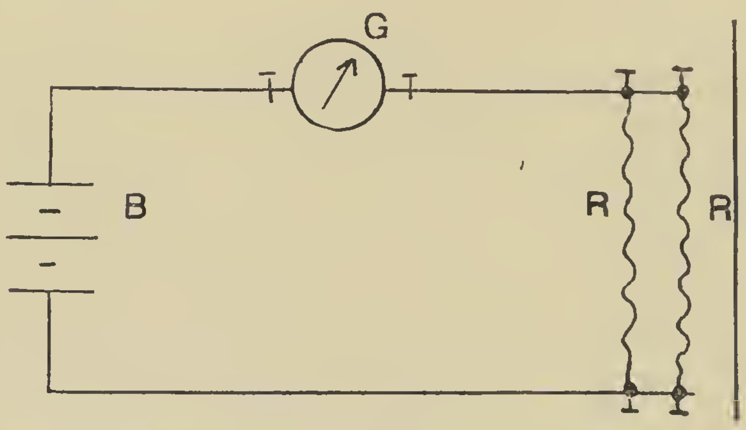

FIG. 38.—SHOWING A SIMPLE CIRCUIT CONTAINING TWO RESISTANCE WIRES IN PARALLEL.

current varies directly as electromotive force, and inversely as the resistance, but also that the current equals the electromotive force divided by the resistance, $C = \frac{EMF}{R}$. This relationship between current, electromotive force, and resistance is known as **Ohm's law**, and this formula may be written in its equivalents: $E = C \times R$, or $R = \frac{E}{C}$.

For these factors certain **units** have been adopted. Each unit is susceptible of practical measurements.

The **ohm** is the name given to the unit of resistance, and the standard unit is represented by the resistance offered at the temperature of melting ice, by a column of pure mercury 1.06

meters high, and with a cross-sectional area of one square millimeter; or it is about the resistance offered by a copper wire $\frac{1}{20}$ of an inch in diameter and 250 feet long.

The **ampère** is the name given to the unit current, and it is the current that, flowing through a solution of silver nitrate, will deposit 0.001118 gram of silver in one second, or in flowing through water will free 0.0000105 gram of hydrogen in one second. (In medical work we use as the unit $\frac{1}{1000}$ ampère, or one milliampère.)

The **volt** is the name given to the unit of pressure of electromotive force, and it is that pressure that, acting steadily upon a conductor whose resistance is one ohm, will produce a current of one ampère. The volt is very nearly the electromotive force of a zinc-copper or a Daniell cell. Expressed in these units, Ohm's law would read: Ampères $= \frac{\text{Volts}}{\text{Ohms}}$.

The **coulomb** is the unit of quantity. It represents the quantity of electricity necessary to set free from water, electrolytically, 0.010384 milligram of hydrogen. The coulomb may be entirely neglected and the ampère alone used, if we consider the time in which a certain number of coulombs flow. We then speak of an ampère-hour, which means one ampère flowing for thirty-six hundred seconds. One ampère-hour is equal to 3600 coulombs, or a current has **one ampère strength** when it gives one coulomb in one second. With these facts in mind we may also use the ampère, which is really only a measure of strength, as a measure of quantity, and then an **ampère** is the volume of current that a pressure of one volt will push through a resistance of one ohm. 1 ampère $= \frac{1 \text{ volt}}{1 \text{ ohm}}$.

In order to make these units still more easily understood, let us compare them with the unit used for ordinary fluids, such as water. We measure water by gallons. This corresponds to the coulomb. A gallon of water is always a gallon, be it under pressure, in motion, or at rest. The same applies to a coulomb. The **coulomb**, as the gallon, is the **absolute unit of quantity.**

Now, supposing we have our gallons of water under pressure in a tank provided with an outlet, so that a regular flow is caused; this would give us a current of water. Similarly an **electric current is electricity in motion.**

Let us suppose that a gallon of water is delivered each second at the outlet of the tank. This would correspond to the ampère, for the **ampère** means **a flow in which one coulomb is delivered in one second.**

If we lead the water through a pipe, it encounters a certain resistance, greater or less as the pipe is small or large. The **conducting wire** in electricity is analogous to the pipe in our water-flow, and the **unit of resistance** is an **ohm.**

To overcome this resistance in such a manner as to cause a flow (or current) that will deliver a certain quantity of water in a certain time requires a certain pressure or motive force. If the pressure in our tank of water be such as to deliver in each second unit quantity (one gallon) against unit resistance, we have, further, a **unit of pressure**; and this is the analogue of our **unit of electromotive force,** namely, **the volt.** Thus, if against a **resistance of one ohm** we have delivered a **current of one ampère,** that is to say, **one coulomb a second,** it indicates the necessary **pressure** in our current source; namely, that of an **electromotive force of one volt.**

Having Ohm's law in mind, it is easy to ascertain the **voltage** required to produce any required current in a wire of given resistance; thus:

1. If we have a wire of 2 ohms resistance, what voltage is required to obtain a current of 18 ampères?

$$C = \frac{E}{R},\ 18 = \frac{E}{2} = 18 \times 2 = E \quad \therefore E = 36.$$

Therefore we require 36 volts.

2. If we have a resistance of ¼ ohm and require a current of 200 ampères, what voltage must we have?

$$200 = \frac{E}{\frac{1}{4}} = 200 \times \frac{1}{4} = E \quad \therefore E = 50.$$

Thus we require 50 volts.

Compound Circuits.—It is only necessary, further, to remember that when conductors are joined in series,—*i. e.*, one to the other, lengthwise,—the total resistance is increased in proportion to the sum of the separate resistances, and therefore the current is proportionally diminished; but if they are placed in parallel, the sectional area is increased, the resistance proportionally diminished, and the current is increased. When a circuit has two or more branches, it is termed a **divided** or **compound circuit.**

Thus if two conductors, A B, C D (Fig. 39), each of 10 ohms resistance, be connected as shown in the illustration, they are said to be in parallel, and the joint resistance of the pair will be $\frac{10}{2}$, or 5 ohms. Similarly if three such wires be connected in parallel, their joint resistance would be $\frac{10}{3}$, or 3.333 + ohms, and so on for any number of parallel wires. The current in such a parallel

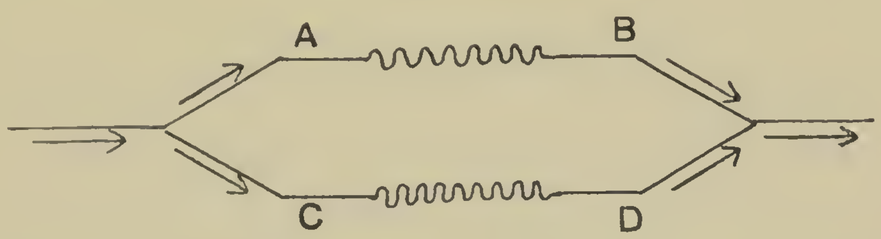

FIG. 39.—SHOWING TWO RESISTANCE WIRES PLACED IN PARALLEL.

arrangement will divide itself between the branches, as shown by the arrows, and this law, which governs the position of current in a compound closed circuit, is one of great importance.

Shunts.—If a current can flow through several paths, as when, for instance, the poles of a battery are connected to several wires, the current will divide itself according to a **law of Kirchhof** (mathematically demonstrable, but upon whose demonstration it is not necessary to enter), so that the strength of each branch current is inversely proportional to the resistance of its branch circuit; or, to express this in a different manner, a branch conductor that is joined to a main conductor carries current in direct proportion to the relation that its own conductivity bears to the conductivity of the main conductor. Thus, if the conductivity of the main conductor be two and that of the secondary

conductor be eight, the joint conductivity will be ten. Ten parts of current will flow through both conductors—two through the main and eight through the secondary conductor. Such a secondary or branch conductor when introduced into a circuit is called a **shunt,** and the circuit determined by it is called a **shunt circuit.**

Variation of Current in Branches of Compound Circuits.—If the conductivity of one of the conductors forming a compound circuit be varied, the current flowing through each of them will be varied in proportion to the resistance thus interposed—*i. e.*,

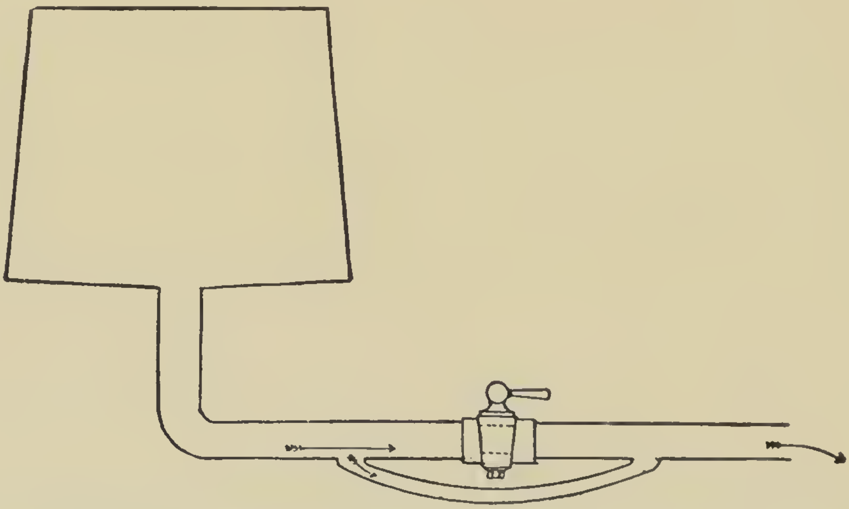

FIG. 40.—SHOWING THE PRINCIPLE OF THE SHUNT AS APPLIED TO WATER.

decreased in the one of augmented resistance, and increased in the others.

This will become clear if we again have recourse to the analogy of the system of water.

From figure 40 it will readily be seen that the water from the tank will flow through the main and the joined pipe proportionately to their conductivity if the stop-cock be open; and correspondingly as the stop-cock is closed in the main (its conductivity lessened, *i. e.*, its resistance increased), less water will flow through it, and more through the joint or shunt. The principle is of the highest importance in electrotherapeutics, as it governs the regulation of current strength in many applications to the human body, especially when street currents are used.

Experimentally, this law may easily be demonstrated to apply to a current of electricity in the following manner: let B (Fig. 41) represent the battery, whose flow of current is limited to about 100 milliampères, and from which a divided conductor carries the current over D to the rheostat R and to the human body R′. A galvanometer is introduced in each of the divided circuits B D R E and B D R′ E. If the resistance in R be made equal to that of R′, the galvanometer will indicate that the currents in both circuits

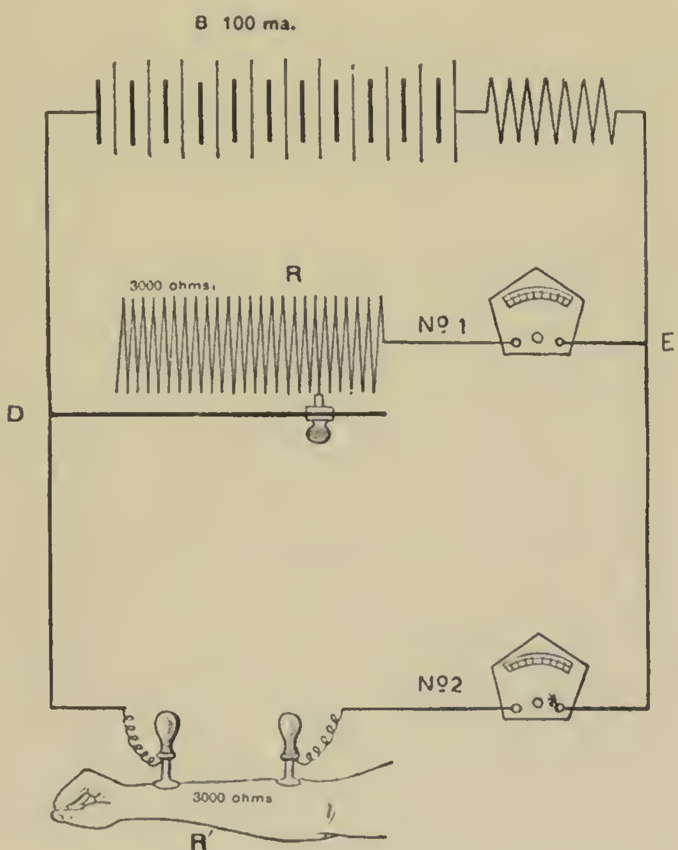

FIG. 41.—SHOWING THE PRINCIPLE OF THE SHUNT AS APPLIED TO ELECTRICITY.

are equal. Assuming the equal resistances to be 3000 ohms, then if we increase the resistance in R to 4000, 5000, etc., the galvanometers will indicate that the currents in R and R′ have become as 3 : 4, 3 : 5, etc.; or if we diminish the resistance in R to 1000, 500, etc., the currents will have become as 3 : 1, 3 : 0.5, etc. In other words, as the resistance in R is increased, the current in R′ is likewise increased, the electricity seeking **the path of least resistance.** Similarly, diminution of resistance in R diminishes the

portion of current that will pass through R′. In both instances the resistance of R′ is presumed to be unaltered.

If, finally, we introduce another galvanometer into the unbranched circuit B D E, it will be found that the current herein is equal to the sum of the current strengths in the branches.

Temperature and Resistance.

We have seen how the total resistance of the circuit is made up, but we must also consider its variability. As all conductors are heated by the passage of a current through them, the most important factor in the variability of resistance is heat. In some cases the raising of the temperature increases the resistance of a conductor ; in other cases it diminishes the resistance. The resistance of metals becomes raised when their temperature is increased, while that of liquids and of nonmetallic substances generally becomes reduced. In a general way it may also be stated that the greater the specific resistance of a body, the more will the temperature be increased in it by the passage of a current and thus reduce its resistivity.

Arrangement of Cells.—With Ohm's law before us we can easily understand how electromotive force may be modified by the arrangement of a number of cells, and also what arrangement of cells is best, in order to obtain the greatest strength of current with a given external resistance.

The following table may be taken as an approximation of the electromotive force of the various cells :

Daniell,	1.07	volts
Leclanché,	1.60	"
Grove,	1.96	"
Bunsen,	1.96	"
Bichromate,	2.14	"

If it be desired to obtain the **greatest electromotive force** from the cells at our disposal, they must be so connected, by *joining the unlike plates* of successive cells, that the electromotive force of each cell will be added to that of the preceding one, as in figure 42. Here the zinc or + element of the first cell is connected with the copper or — element of the second cell, and the

zinc of the latter is joined to the copper of the third cell ; the copper of the first cell, and the zinc of the third cell, being left free to carry the conducting wires terminating in the + and — poles, respectively. Cells so arranged are said to be **in series** ; their respective resistances are joined lengthwise and thus added to each other. If E represents the electromotive force of one cell, then 3 E represents the electromotive force of the three cells figured, and n E represents the electromotive force of n cells similarly connected.

The **total resistance** of a circuit being made up of the resistance of the cells (internal resistance) and the resistance of the path (conducting wires and objects interposed) between the terminal plates outside of the battery (external resistance), let us represent the former by r and the latter by R ; then Ohm's law would read $C = \frac{E}{R+r}$.

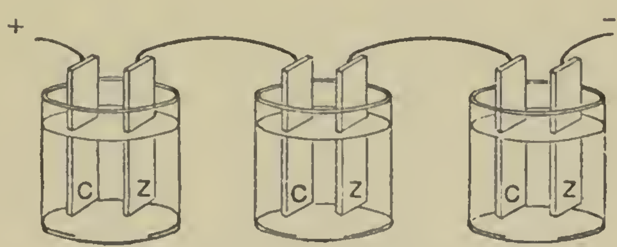

FIG. 42.—CELLS ARRANGED IN SERIES.

But if r be the resistance of one cell and E be the electromotive force of one cell, while R represents the resistance of the entire external circuit, we must, when a number of such cells are in series, speak of n E and n r, so that the formula would read : $C = \frac{n\,E}{R + n\,r}$; or, to put this in figures, if the electromotive force of a single cell be two volts and its resistance be five ohms, while the resistance of the external circuit is made up of a short thick wire of practically no resistance, then the current obtained would be equal to $C = \frac{E}{r}$, $C = \frac{2}{5}$, or $\frac{2}{5}$ ampère. If, now, we take ten such cells and join them in series, the current through the same external resistance would be $C = \frac{10 \times 2}{10 \times 5} = \frac{20}{50}$, or $\frac{2}{5}$ of an ampère, the same as with one cell. Thus we see that the connection of cells in series adds to the internal resistance of the battery, and that with a negligible external resistance we obtain thereby

no increase of current. If, however, instead of no external resistance we take a large external resistance,—for instance, a portion of the human body of say 1000 ohms,—the one cell would give us $C = \frac{2}{5 + 1000} = \frac{2}{1005}$, or about $\frac{1}{500}$ ampère, when ten cells would give us $C = \frac{10 \times 2}{(10 \times 5) + 1000} = \frac{20}{1050}$, or about $\frac{1}{50}$ ampère.

With a large external resistance, the addition of various small internal resistances becomes almost negligible.

To obtain **the greatest volume** of current from a given number of cells in short circuit a different arrangement is necessary. All that has previously been said about resistance is, of course, applicable to internal, as well as to external, resistance. In the one, as in the other, increasing the sectional area of a conductor

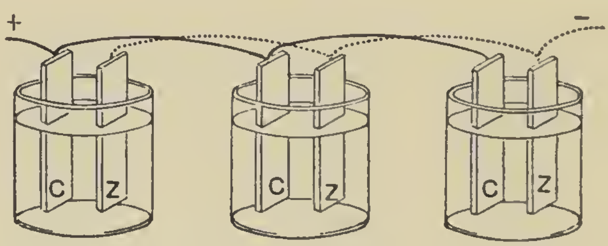

FIG. 43.—CELLS ARRANGED IN PARALLEL.

decreases the resistance. If this area be doubled, the resistance will be reduced one-half. We could, therefore, by doubling the size of a cell,—that is, doubling the size of the elements and the quantity of fluid,—halve the internal resistance of such a cell. The same result can be obtained by joining the similar plates of two or more cells. Thus if, as in figure 43, we join the carbons of three cells by wires of practically no resistance, and join the zincs in the same way, the three cells so joined will act as one cell of threefold size (see also Fig. 44), having, therefore, an electromotive force of only one cell, but, on the other hand, having but one-third the resistance of one cell. Cells so arranged are said to be **in parallel.**

Taking the figures already made use of, a cell of two volts with an internal resistance of five ohms, and with practically no external resistance, would, as we have seen, give us $\frac{2}{5}$ of an ampère. If,

now, taking ten such cells, instead of joining them in series we join them in parallel, the current obtained would be that of one cell having one-tenth the internal resistance; or $C = \frac{2}{\frac{5}{10}} = \frac{2}{\frac{1}{2}} = 4$ ampères, against $\frac{2}{5}$ of an ampère obtained by joining the same ten cells in series.

Under the same circumstances, with an external resistance of 1000 ohms we should, however, obtain $C = \frac{2}{1000 + \frac{5}{10}}$, or only about $\frac{1}{500}$ of an ampère, against $\frac{1}{50}$ of an ampère obtained by joining them in series. Therefore, as joining cells in parallel diminishes the internal resistance but does not increase the electro-

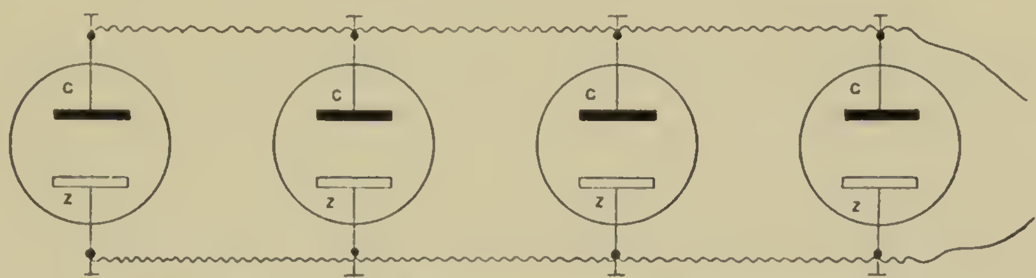

FIG. 44.—DIAGRAM OF CELLS ARRANGED IN PARALLEL.

motive force, the current strength in such an arrangement will vary inversely as the external resistance.

These methods of joining cells may be combined in various ways, and thus the electromotive force and the internal resistance be altered. Such combination is called **multiple series.** A good practical rule for obtaining the greatest current from a given number of cells in a given case is so to group the cells that the internal resistance of the battery approximates as closely as possible the resistance of the external circuit.

CHAPTER IV

EFFECTS OF THE ELECTRIC CURRENT

Physical, Chemical, and Physiologic Effects. Electrolysis. Polarization Electromagnetic Effects. Magnetic Field. Electric Osmosis. Thermic Action. Induction. Measurement. Voltameter. Ammeter. Voltmeter. Resistance Coils. Wheatstone Bridge. Ohmmeter.

All currents, no matter what their source, produce the same effects, namely, physical, chemical, and physiologic. As most of these effects can best be studied with the dynamic currents, we shall, notwithstanding that some of them have already been alluded to, describe them here in full, with the exception of the physiologic effects, which will be treated of in that part of the book devoted to electrophysiology and electropathology.

The **chemical effects** are those of electrolysis and polarization. The **physical effects** are magnetic, mechanical, thermic, and dynamic.

Chemical Effects of the Galvanic Current.

1. **Electrolytic Effects.**—Faraday gave the name electrolysis to the chemical decomposition caused by electricity, and called the body that is, or that is to be, decomposed, the electrolyte,[1] and the products of such decomposition, ions. Hence that part of the electrolyte that, through decomposition, arises at the positive pole is called the anion, and that found at the negative pole, the kation. As a result of numerous experiments, Faraday concluded that the quantity of electrolyte decomposed is directly proportional to the strength of the current. Upon this is based the voltameter.

In the chemical decomposition of water, hydrogen is given off

[1] This term "electrolyte" must not be confounded with the term previously applied to battery fluid. The latter is the active agent in producing electricity, while the former is acted upon passively. Both are broken up chemically, but the circumstances of the electrolysis differ.

at the negative pole, or kathode, oxygen at the positive pole, or anode. In general, acids go to the anode, while alkalies and bases go to the kathode.

2. **Polarization Effects.**—In close relationship to the electrolytic effects of the current stand its polarizing effects. In the organism and in pieces of animal tissue, at the moment of breaking the galvanic current, secondary or polarization currents arise, and their presence can be demonstrated by delicate indicating instruments. These currents are opposed to the original currents. They are undoubtedly analogous to the polarization currents arising in inorganic substances.

Magnetic Effects and Magnetic Field of the Galvanic Current.

If the wire through which the galvanic current is flowing be strewn with iron filings, these filings will remain attached to the wire as to a **magnet.** If a straight wire through which a galvanic current is flowing be brought near to a magnetic needle, above or below it, but parallel to its position of rest,—that is, in the magnetic meridian,—the needle will be deflected from its position of rest, and will tend to take up a position at a right angle to that of rest and that of its deflecting circuit.

The **direction** in which the needle will be deflected may always be predetermined according to Ampère's rule, which says: 'Imagine yourself swimming in the electric current, so that the direction of the current is from the feet to the head, and that your face be turned toward the needle; then the pole of the needle that points to the north will always be deflected in the direction of the extended left hand of the swimmer.' (See Figs. 45, 46, 47.)

At the same time that Ampère formulated the foregoing rule for recognizing the deflecting direction of the current, he furthermore proposed to utilize the arc of deflection of the needle for the measurement of **current strength,** and called the apparatus that renders this possible, a galvanometer.

Magnetic Field.—We know, from practical experience, that a magnet acts upon a piece of soft iron or upon a magnet placed at a distance, by attraction or repulsion. Whereas formerly it was as-

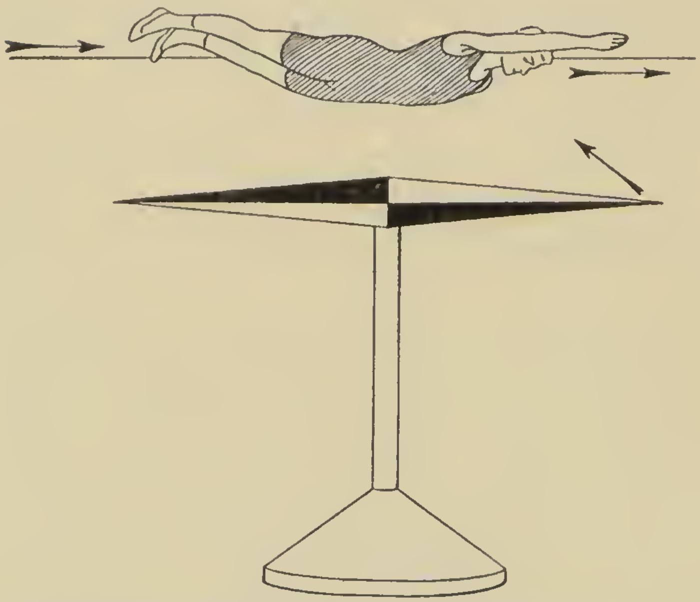

FIG. 45.—ILLUSTRATING AMPÈRE'S RULE OF THE DEFLECTION OF A MAGNETIC NEEDLE.

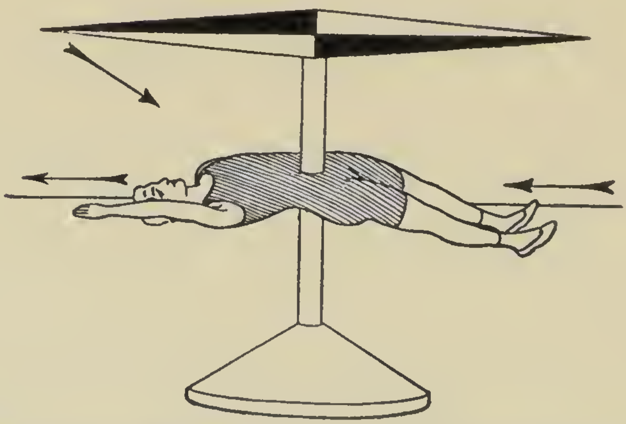

FIG. 46.—ILLUSTRATING AMPÈRE'S RULE OF THE DEFLECTION OF A MAGNETIC NEEDLE.

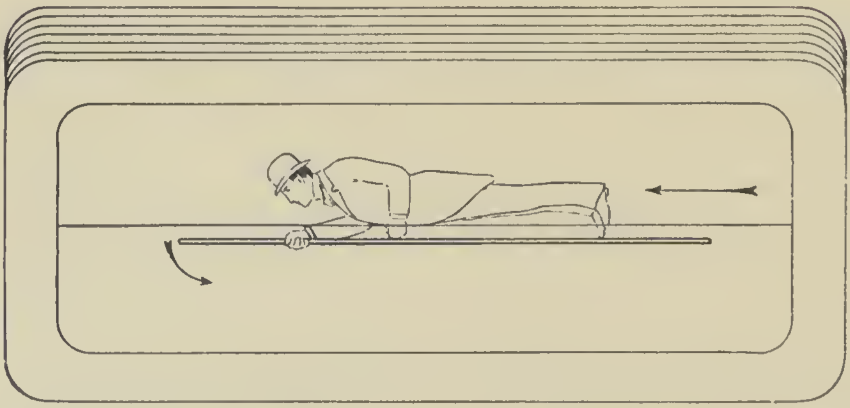

FIG. 47.—ILLUSTRATING AMPÈRE'S RULE OF THE DEFLECTION OF A MAGNETIC NEEDLE.

sumed that this action was due to the creation of an attraction or repulsion force at a distance, it is now assumed that by its mere presence a magnet, in some way of which we are ignorant, modifies the surrounding medium. Theoretically, this modification covers an infinite distance, but practically, its distance is limited and the extent is governed by the strength of the magnet. The extent of the medium so modified is called the **magnetic field.** A small magnetic needle, suspended by a silk thread so as to swing freely and horizontally, will, if brought into a magnetic field, be deflected from its north-south position with more or less rapidity, and in a different direction, according to the position of the field in which it is placed—that is, according to the direction and intensity of the force that impels it to leave its position of rest. If such a needle be successively placed at each point of a magnetic field, the direction and intensity of the magnetic force at each point may be determined. By agreement, therefore, the magnetic field is represented by curved and by straight lines, which have been obtained by making them, at each point, take the direction that the magnetic needle would take if placed at that point; furthermore, these lines are so arranged that at each point their distance from adjoining lines is inversely proportional to the magnetic action at this point; so that the greater the magnetic action, the closer do the lines approach one another. This is, of course, a purely conventional matter, for there should be a line for every point in the space surrounding the magnet. These lines are designated as *lines of force*.

Electromagnets.—The knowledge of magnetic properties of a circuit is, however, considerably older than that just detailed. Fully twenty years prior to the discovery of the deflection of a magnetic needle by the galvanic current, it was known that a piece of iron introduced into a galvanic circuit for a long period of time finally became magnetic. If a copper wire is wound around a cylinder of wood or pasteboard so that each turn of wire is well insulated from the adjoining turns, and in the hollow of such a spiral a solid cylinder of soft iron is introduced, then this iron becomes magnetic when the current flows through the surrounding wire, losing its magnetism when the current ceases. Such a magnet is called an **electromagnet.**

Mechanical Effects of the Electric Currrent.

In the circuit, the **mechanical effects** of the galvanic current are of a molecular or of a molar nature. The molecular effects become evidenced mostly by structural changes in the traversed conductor; thus, copper wires that are frequently traversed by a current, in time have their conductivity altered. The molar action of galvanic electricity is shown by electric osmosis —the transfer of fluids, through porous partitions, from anode to kathode (**cataphoresis**).

Calorific Effects of the Electric Current.

The **thermic actions** of the galvanic current have already been alluded to. If, in the circuit of a battery of low resistance, one whose cells are joined in parallel, a fine platinum wire be introduced, the wire will, upon traversal of the current, become heated to a glow. The quantity of heat thus developed in a circuit in a certain time has been found proportional to the resistance of the current circuit and to the square of the current's strength.

It is necessary, however, to mention here, in connection with calorific effects, that if two points of different potential be connected by a wire conductor and this wire be consequently traversed by a current of electricity, heat is produced, which manifests itself, more or less, by an increase of temperature in the conductor. This effect ceases almost immediately if an electric equilibrium be re-established, but it is kept up if the points connected be maintained at different potentials. The heat thus produced may be so great as to cause an incandescence of the wire. The degree of heat produced will depend upon the quantity of electricity that traverses the wire and upon the resistance of this conductor.

This question of calorification is important in galvanocautery and in lighting.

Dynamic Effects of the Electric Current.

These depend upon the fact that electric currents act upon each other or upon magnets, or, conversely, that magnets act upon electric currents. This subject will be further elucidated under the head of **dynamic induction**.

MEASUREMENT OF THE ELECTRIC CURRENT AND MEASURING INSTRUMENTS.

As we have already seen,* there are three prime quantities to measure in the electric current—viz., **electromotive force**, which is measured by the unit called the volt; **current**, which is measured by the unit called the ampère; and **resistance**, which is measured by the unit called the ohm.

For the measurement of an electric current, various effects of the current may be made use of: thus, a current may be measured by electrolysis, by its magnetic action, and by its calorific properties.

Electrolytic Measurement.

The apparatus that is used to measure a current by means of its electrolytic action upon liquid is called a **voltameter** (not to be confounded with voltmeter), and may consist, for example, of a vessel containing acidulated water, in which are two strips of platinum, the lower end of each being connected through the bottom of the vessel with a pole of a battery, the upper and free end of each being covered by an inverted test-tube that has been filled with acidulated water prior to such inversion. (See Fig. 48.) When the current then flows, the gas—hydrogen or oxygen—formed at each platinum strip collects in the respective tubes, forcing out the water. In the case here assumed one tube fills with gas twice as quickly as the other, because water consists of two parts of hydrogen and one part of oxygen; the (—) strip from which hydrogen is liberated gives off twice the volume of gas in a stated time that the other (+) strip gives off of oxygen. No matter what the composition of the electrolyte, the same quantity of electric current will give rise to the same quantity of electric decomposition in a given time.

FIG. 48.—A VOLTAMETER.

What we have now measured, therefore, is **quantity**, or, in other words, coulombs. If we have 10 ampères flowing for one minute, or 1 ampère for ten minutes, the quantity of electricity

will still be registered the same—viz., 600 coulombs. This result is easily arrived at. It will be remembered that one ampère delivers one coulomb each second. Then in one minute 60 coulombs, and in ten minutes 600 coulombs, must be delivered. Conversely, 10 ampères deliver 10 coulombs each second; therefore in one minute a current of 10 ampères delivers 60 times 10, or 600 coulombs.

Inasmuch as the current flowing through any section of a circuit is the same as that flowing through any other section, the following electrolytic laws may be deduced:

1. The quantity of chemical action is the same at all points of a circuit.

2. The quantity of an ion liberated at an electrode in a given time is proportional to the quantity of the current passing in a given time (ampères).

3. The weight of an ion liberated at an electrode in a given time is equal to the quantity of the current multiplied by the electrochemical equivalent of the ion.

Hence by this electrochemical decomposition the coulomb may practically be measured, according to the nature of the electrolyte, by measurement of the quantity or of the weight of the liberated ion.

Measurement by Magnetic Action.

We have seen that upon the deflection of a magnetic needle from its normal position by a current of electricity depends the construction of the **galvanometer,** and that such a galvanometer will not only show that a current is passing, but will measure its strength and indicate its direction. According to Ampère's law, it may easily be demonstrated that if a current pass above the needle, and parallel to it, from south to north, the north pole of a magnetic needle will be deflected to the west, while if the current flow in the same direction, but underneath the needle, the north pole will be deflected to the east. When the current flows above from north to south, the north pole will be deflected to the east, and if it flows in the same direction below it, the needle swings to the west. Accordingly, a current, passing through a wire that encircles such a magnetic needle, which is so balanced that it may swing easily, will

flow in one direction in the part of the wire above the needle, and in the opposite direction in the part of the wire below the needle, and, therefore, tend to deflect the needle in one and the same direction. Hence the encircling wire produces a summation of effects, and causes the needle to swing in one direction with double the force that a current passing merely above or below would deflect it.

In figure 49, let a b b′ a′ represent a wire through which a current is flowing in the direction indicated by the arrows. It is clear that if the current were flowing above and below in the same direction,—*i. e.*, from a to b above, and from a′ to b′ below,—the one current would oppose the other and the needle would be unaffected; but as the current below the needle flows from b′ to a′, both the upper and lower parts of the current must exert their force upon the needle in the same direction.

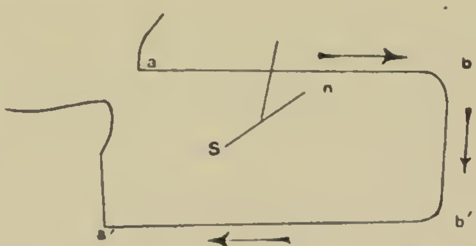

FIG. 49.—SHOWING THE PRINCIPLE OF THE MULTIPLICATOR.

This effect may be increased by increasing the number of turns of wire, and it would be directly multiplied according to the number of turns, were it not for the fact that by such an increase in turns of wire the resistance of the circuit is also increased. Such an arrangement of turns around a magnetic needle is called a **multiplicator**, and upon this the construction of the majority of current meters depends.

The needle of all such instruments is, however, influenced by the magnetism of the earth, and this necessitates placing the instrument so that the needle shall point magnetically north and south. This is often impracticable, and therefore it becomes necessary to neutralize in some way the effect of the earth's magnetism upon the needle. This can be effected by taking two similar needles, placing them above and parallel to each other, and connecting them rigidly, so

that their poles point in opposite directions, as is shown in figure 50. Such a pair of magnetized needles is called an **astatic system.**

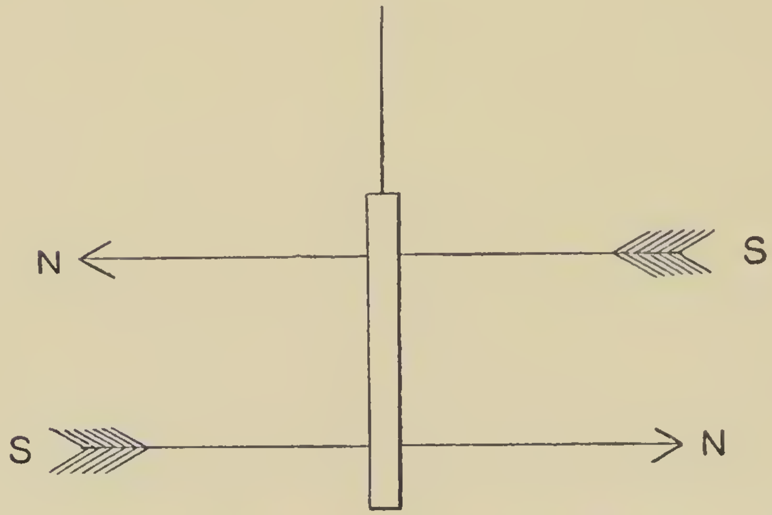

FIG. 50.—AN ASTATIC SYSTEM OF NEEDLES.

Perfect astaticism is a mechanical impossibility; the majority of such systems tend to come to rest in a more or less east-west posi-

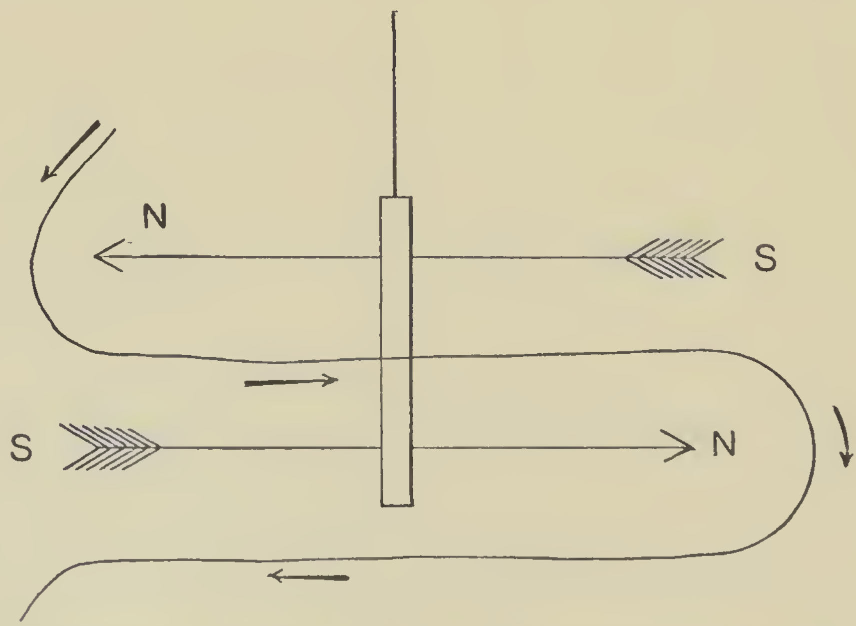

FIG. 51.—SHOWING THE METHOD OF WINDING COIL IN THE ORIGINAL FORM OF ASTATIC GALVANOMETER.

tion, just as a very weak magnet would; while a perfect astatic system should remain pointed in any direction in which it is placed,

without having any tendency to alter its position. A galvanometer constructed with such a system is called an **astatic galvanometer,** and the system herein is deflected by a current passing through a coil, the same as that previously described.

In the instruments of older make, the coil is usually so wound that it passes above and below the lower needle, and only below the upper one, as is shown in figure 51.

The current through the coil will act so as to turn each needle of the system in the same direction.

In more recent instruments both needles are surrounded by coils of wire, so that we have a multiplied effect, as is shown in figure 52.

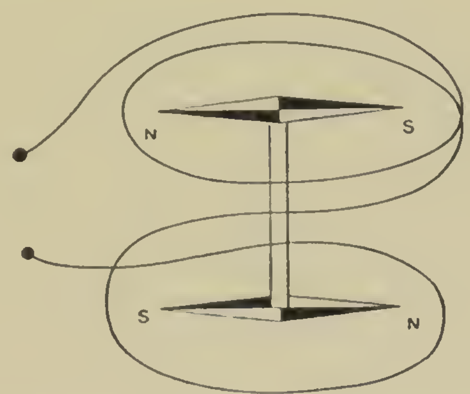

FIG. 52.—SHOWING THE METHOD OF WINDING COIL IN IMPROVED FORM OF ASTATIC GALVANOMETER.

The **mirror galvanometer** is an instrument used for the measurement of very small currents—currents so small that their reading upon the scale would be difficult on account of the slight deflection of the needle; and for this purpose the principle governing reflected light is made use of.

A ray of light striking a perfectly plane mirror will be reflected from the mirror at an angle equal to the angle of incidence. A very small and light mirror is therefore attached to the needle of a galvanometer, and moves when the needle moves. A ray of light made to strike the mirror perpendicularly, when the needle stands at zero, will be reflected straight back. If, however, the needle, and with it the mirror, be moved through any angle, the reflected ray will no longer be reflected perpendicularly, but will be reflected at an angle dependent upon the deflection of the needle. Thus,

if A o B (Fig. 53) be a semicircular scale, and at o there be a small hole through which a ray of light passes and falls perpendicularly upon the mirror m n, then the ray will be reflected directly back

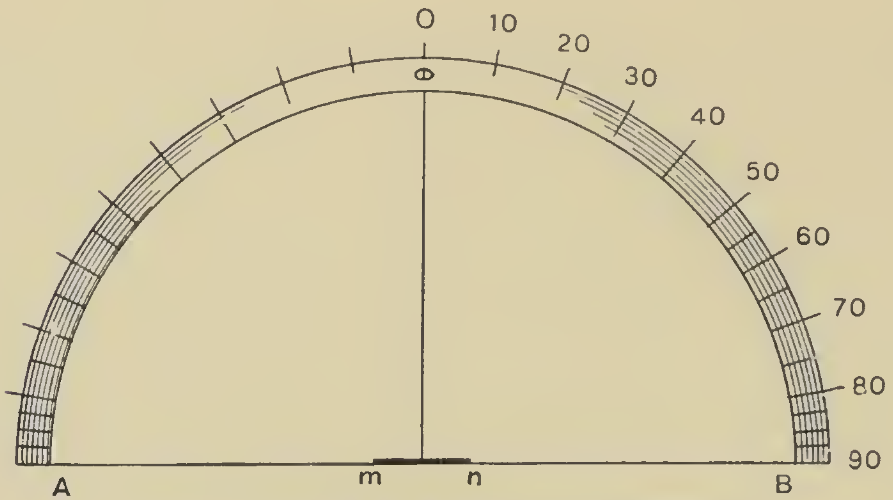

FIG. 53.—SCALE OF MIRROR GALVANOMETER.

through the hole so long as the position of the mirror remains unchanged; if, however, the mirror be tilted, as shown in figure 54, the light striking the mirror at an angle of say 20 degrees, it

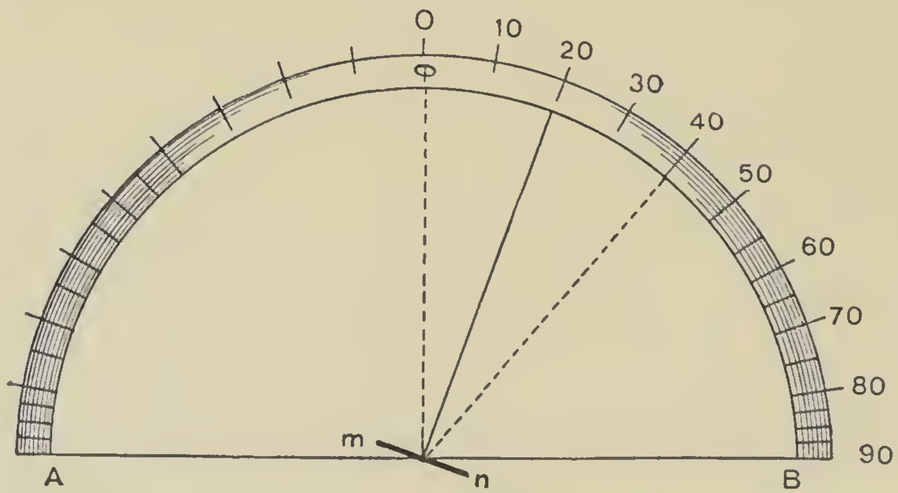

FIG. 54.—SHOWING COURSE OF DEFLECTED RAY ON SCALE OF MIRROR GALVANOMETER.

will also be reflected at an angle of 20 degrees, and the spot of light will be seen on the scale at a point marked 40.

The angular deflection of a reflected ray is double that of the angle of the mirror that deflects it, and we are thereby enabled to

divide the scale into larger divisions, and thus obtain a more accurate reading.

For practical purposes, especially for rapid reading, the oscillations of the magnetic needle must be decreased. Such a decrease is obtained by damping; and instruments so damped are called dead beat. The damping may be effected in various ways: as by placing around a needle pieces of copper or a mass of copper; or by immersing the needle in a cell filled with a liquid; or by attaching wings of mica to the needle.

So, also, it is often necessary to measure currents so large that the instrument would be endangered by their use. To guard against such injury and to increase the reading capacity of the instrument, a shunt is introduced; that is to say, another path is furnished that is parallel to the first and through which the current may flow. The principle of the shunt has already been explained (see derived or shunt currents, p. 65), and according to this principle we can arrange the resistance in the shunt so that any desired portion of the current will pass through this, while the remainder passes through the galvanometer. Thus, for example, if the resistance of shunt and galvanometer is made to equal 10, and it is desired that $\frac{9}{10}$ of the current pass through the shunt and only $\frac{1}{10}$ through the galvanometer, then the resistance of the galvanometer must be 9 times as great as that in the shunt.

The **differential galvanometer** is an instrument so constructed that its needle is acted upon by two equal coils wound so as to oppose each other. When equal currents flow through the coils, the action of one current neutralizes the action of the other, and the needle remains at rest. Any difference in the equality of the current strengths will cause a deflection that will, of course, be proportional to the inequality.

Galvanometers that are so arranged as actually to measure the current are called **ampèremeters**, or this term is contracted to **ammeters**.

A practical **ammeter** must, of course, be less delicate in construction than the instruments thus far spoken of, as we must be in a position to measure very large currents. The principles upon which such an instrument is constructed are very simple. Above

all, the scale of the instrument must be so divided that it may be read directly in ampères, every number marked thereon representing an ampère. The further principles are represented in figure 55. Thus, let N S represent a strong permanent magnet, between the poles of which a small needle, S N, is suspended; the position of rest of this needle will be controlled by the magnet, while a light pointer, carried by the needle, will indicate its position of rest, or zero mark, upon a scale provided for this purpose. Above and below the needle is a coil, C C′, through which the current to be measured is made to flow. By such a current the needle will be deflected from its position of rest, and the pointer from the zero mark of the scale. The position that the pointer occupies upon the scale when 1, 2, 3, 4, etc., ampères of current flow through the coils may then be marked accordingly, and a scale thereby calibrated for direct reading.

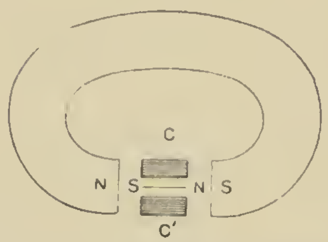

FIG. 55.—SHOWING PRINCIPLE OF THE AMMETER.

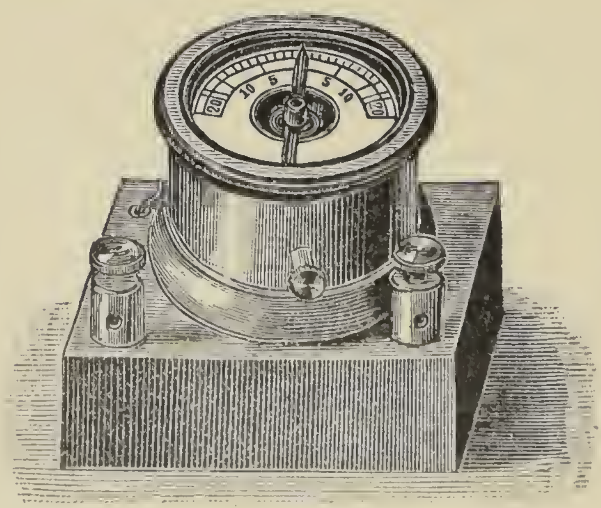
FIG. 56.—AMMETER.

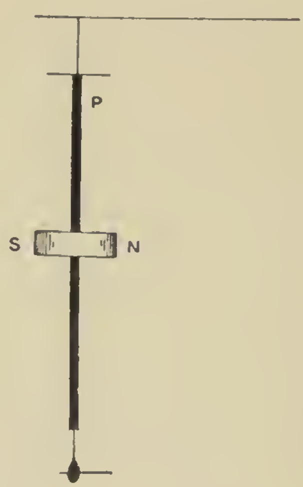

FIG. 56 A.—ARRANGEMENT OF AMMETER NEEDLE.

Various means may be employed to hold the needle in a fixed, or zero, position; a permanent magnet, an electromagnet, a spring, or the action of gravity is used to accomplish this.

A form of **ammeter** frequently used is shown in figure 56. A short needle, N S, is fixed on a shaft, P (Fig. 56 A), which turns in

jewel cups and is mounted between the poles of two strong magnets. (See Fig. 57.)

A form of instrument that is practically free from the magnetic influence of the earth, and that is extensively used, is the **Weston ammeter.** This instrument and its working parts are shown in figures 58 and 59. Here the coil C is placed between the poles of the permanent magnet M M M M (only visible in Fig. 58). Coil springs S S hold the coil in the zero position, and carry the current to be measured into, and out of, the coil C. So long as

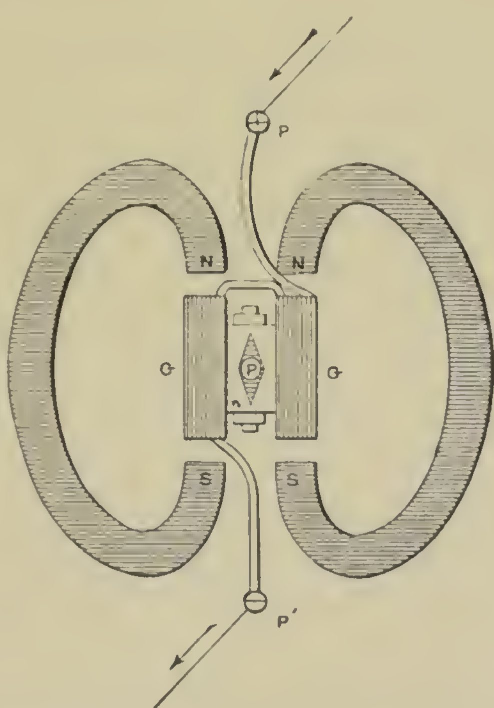

FIG. 57.—SHOWING HOW THE AMMETER NEEDLE IS MOUNTED.

no current flows through the coil, a pointer, R, attached thereto, remains at the zero point of the scale; so soon, however, as a current passes through the coil, the electromagnetic action thus set up causes the pointer to move through a certain distance upon the scale, and this distance can be read off directly, and indicates the strength of the flowing current. This instrument is usually provided with a shunt, and then carries two scales, upon one of which the entire current may be read, and upon the other the portion that passes through the shunt. Either reading may be

selected by means of the special mechanism that introduces the shunt or throws it out.

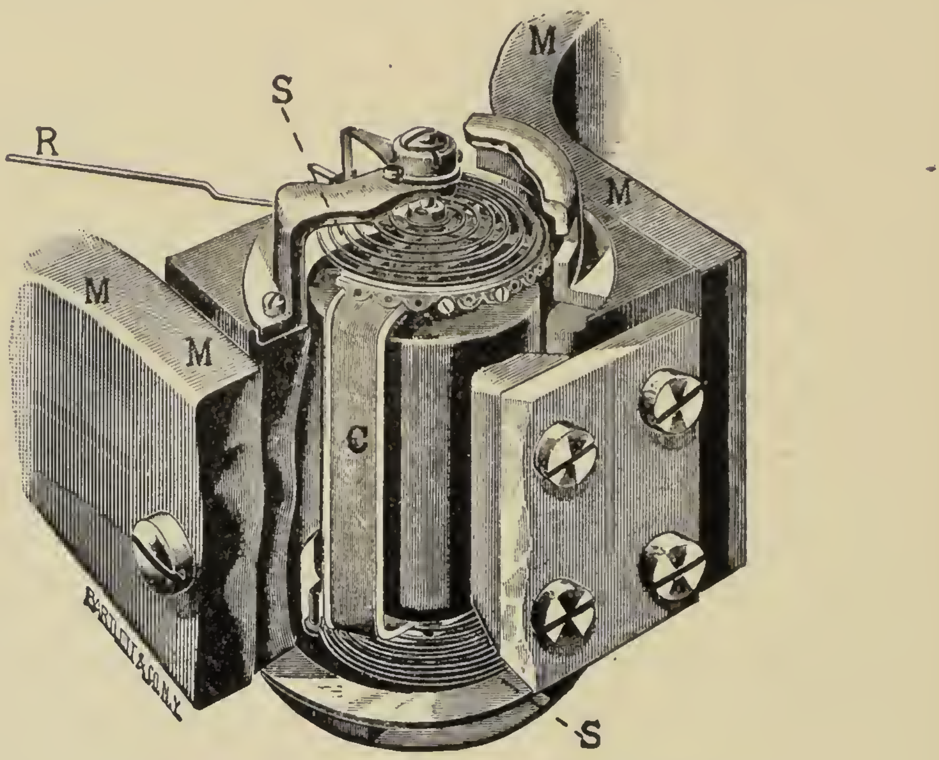

FIG. 58.—WESTON'S AMMETER, SHOWING WORKING PARTS.

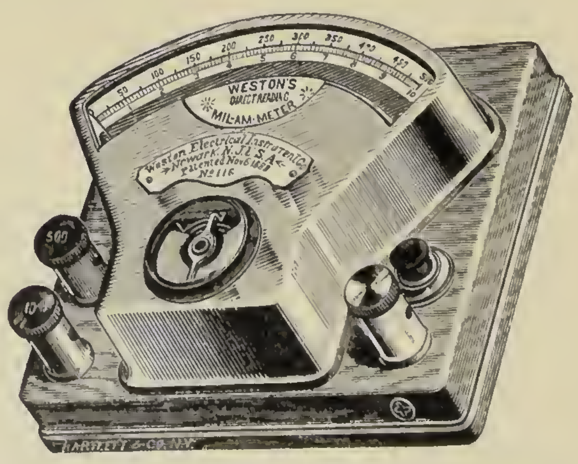

FIG. 59.—WESTON'S AMMETER COMPLETE.

Voltmeters.

In addition to measuring the current strength, it is also necessary to measure the current pressure, or **voltage**. The instrument used is called a **voltmeter**, and although differing from the ammeter in construction, need not do so in principle.

For a clear comprehension of the construction of a voltmeter, it

is necessary to remember the underlying principle of all measurement—that the means used to measure must not alter that which is measured. As, however, all measuring instruments have some resistance, the introduction of such an instrument into a circuit will change somewhat the conditions that we are dealing with.

An ammeter must, in order to be used, be placed in the circuit so that the current will flow directly through it; that is to say, it must be placed in series with the remainder of the circuit, and therefore adds resistance. If the resistance of such an instrument be large and the resistance of the remainder of the circuit be small, while the pressure remains constant, the current obtained would be materially lessened. It is therefore necessary, in order to measure the real current strength, to make the resistance of an ammeter as small as possible as compared with the resistance of the remainder of the circuit.

Measurement of Pressure.

Pressure may be measured, in an analogous manner to current strength, by the differential or by the comparative method. Thus, in the former case, the difference between certain pressures, acting upon a magnetic needle through different equal paths, may be calculated. In the latter case the needle will not be moved if the pressures be equal; and, furthermore, a certain unknown pressure may be determined if its effects be compared with those of a certain known pressure. Governing all methods is the fact, which must receive due consideration, that if the outflow of the current is more rapid than the inflow, the pressure, or electromotive force, cannot remain constant. Thus, referring again to the analogy of water in a tank, the pressure in the tank will depend upon the height of the body of water that it contains. Let the water (Fig. 60) be supplied from the top by means of an inlet, and be allowed to run out at the bottom by means of many outlets; if all the outlets be open, the water will escape more rapidly than it accumulates, and the pressure will diminish. It is therefore necessary, in order to keep the pressure in such a tank constant, to diminish the outflow and to regulate it in accordance with the inflow.

The desideratum is the same with electricity, and the method

of attaining it is the same. In the case of the water we turn off some of the stop-cocks; in the case of electricity we introduce resistance and take a smaller current. The smaller we desire to make the current, the more resistance must be introduced; that is, in order to measure electromotive force correctly we must have a small current, hence a large resistance. Practically, then, we require an ammeter of large resistance in order to measure electromotive force.

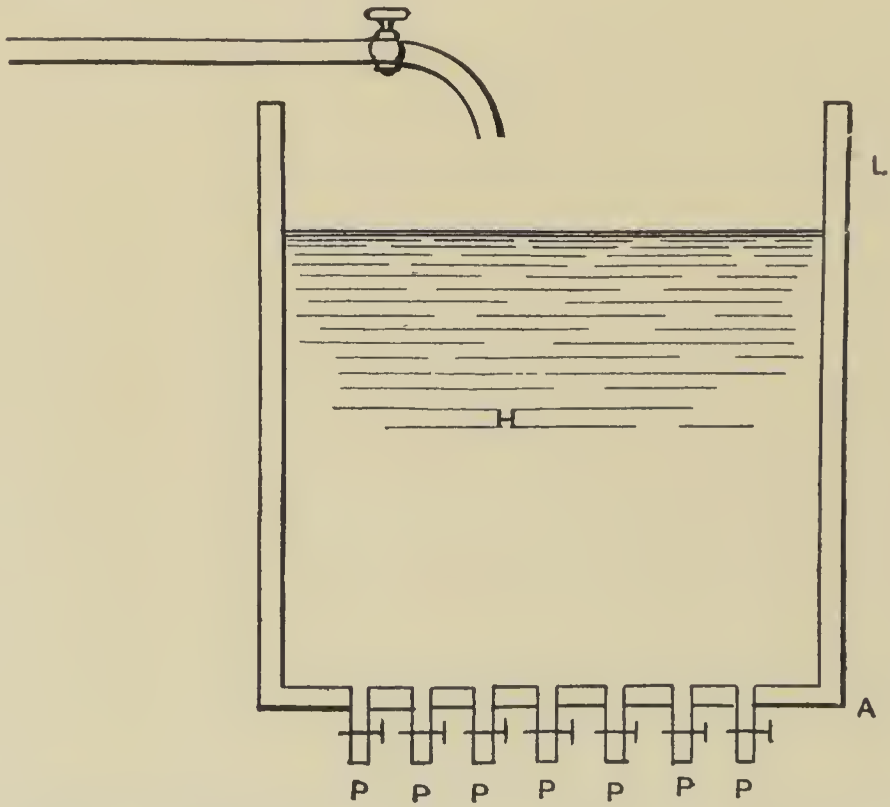

FIG. 60.—SHOWING THE RELATION OF PRESSURE TO OUTFLOW IN A WATER TANK.

The formula, $C = \frac{EMF}{R}$, may be translated into; current varies directly as electromotive force, and inversely as resistance, so that if electromotive force is in any way altered, current will be altered correspondingly if resistance remain unchanged.

The resistance of an ammeter or a voltmeter remains practically constant. If, then, we take such a voltmeter (an ammeter of high resistance) and join it by its terminals to the two points of a circuit whose difference of potential we wish to ascertain, then $C = \frac{EMF}{R}$;

the same instrument, joined similarily to any other two points, will give us $C' = \frac{E'M'F'}{R}$; both equations compared mean that the indications of current C C′ will be proportional to the differences of E M F and E′ M′ F′, and this difference will be given in volts, if a scale be calibrated for this purpose. If C′ be 2, 3, or 4 times as great or small as C, then E′ will be 2, 3, or 4 times greater or

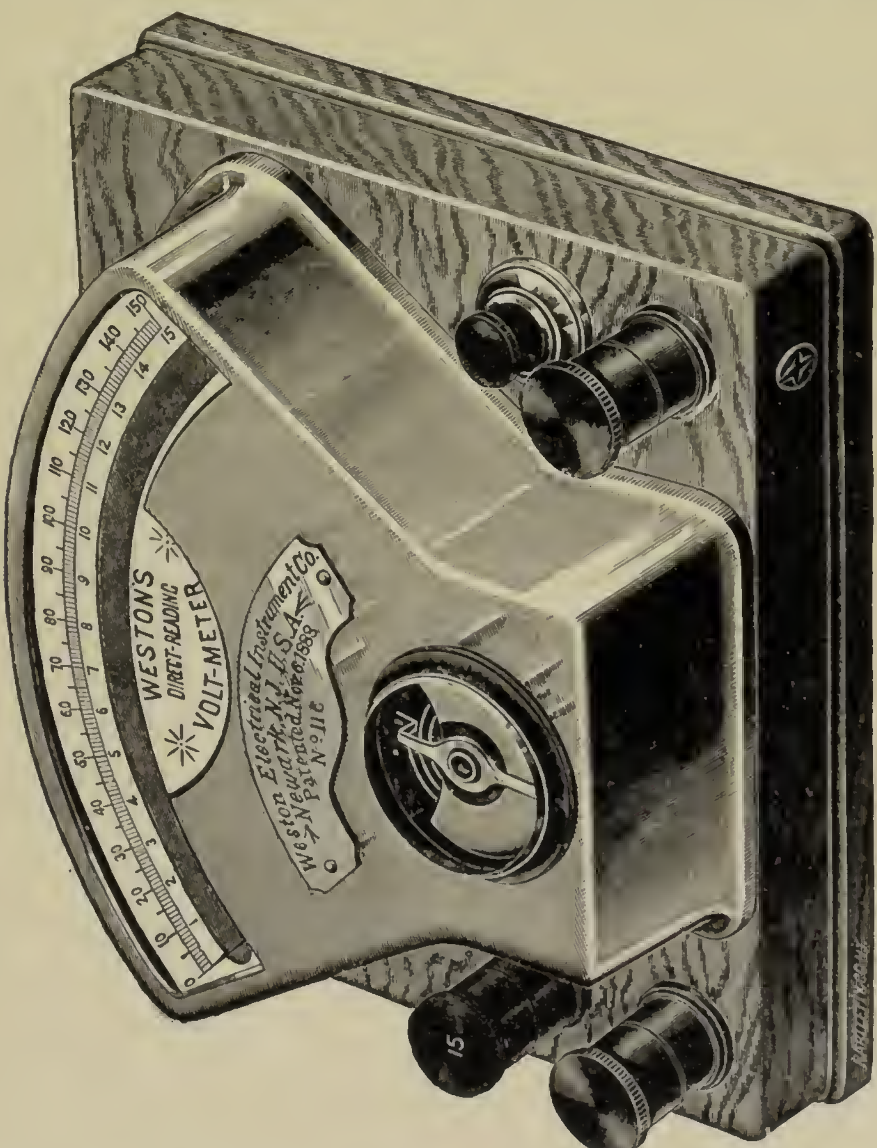

FIG. 61.—WESTON'S VOLTMETER.

smaller than E. What we require to know, in order to make a scale, is the E M F "x" that will give a current "y." If we have a current $2y$, the pressure must be $2x$, etc.

While here, again, there are many good instruments, the best is, no doubt, the Weston voltmeter, which is constructed upon

the same principle as the ammeter of the same name ; but which has a high resistance coil of fine wire (Fig. 61), placed in series with the moving coil, instead of the shunt coil of low resistance placed parallel to it. Here, also, two sets of readings may be obtained by winding the high resistance coil in two sections of different lengths, and hence having different resistances. Every instrument must be adapted to the purpose for which it is used, and these or similar instruments are the ones best adapted for the currents used in medicine. It is, therefore, unnecessary to enter upon a description of voltmeters essentially different in construction and principle.

Measurement of Resistance.

The last quantity, the measurement of which we must elucidate, is **resistance**, the unit of which is the ohm, represented by the resistance of a column of mercury 1.06 meters in height, with a cross-section of 1 square millimeter, at the temperature of melting ice ; or it is represented by the resistance of a copper wire $\frac{1}{20}$ of an inch in diameter and 250 feet long.

As mercury standards are impracticable, standards of some other, usually a metallic, conductor are employed. Such instruments are called **resistance coils**, and they may be made, according to their length and thickness, to represent any desired part of an ohm or any number of ohms. No matter what materials are used, certain basic principles must be followed in the construction of such a resistance coil.

1. Its resistance must be carefully measured by a certain standard of resistance.

2. It must be constructed of material whose resistance changes but slightly with change of temperature.

3. It must be insulated from adjoining conductors and protected against moisture, and if wire coils are used, the wire must be doubled back upon itself, to prevent self-induction.

The construction of such a set of resistance coils is best studied with the aid of a diagram (Fig. 62). A A A A are thick blocks of metal ; F is a plug of metal that fits into the conic holes bored into the blocks A A A A, and whose upper part is of ebonite. The plate C C covers and insulates the coils H H H. These coils

are made up of wire so wound as to double upon itself, in order to prevent self-induction. Each coil connects two metal rods of sufficient thickness to offer no resistance to the current, and one of these rods is attached above to the first block, the second to the adjoining block, etc. ; the first rod of the second coil is connected to the distal end of the second block, the second rod to the proximal end of the adjoining block, etc. The coil of wire connecting each set of rods has been carefully measured. These sets (coils and rods) of known resistance may be substituted for any unknown resistance, and the unknown resistance thereby measured. It will be seen that if a plug be introduced into any hole, the current taking the path of least resistance will flow through the metal

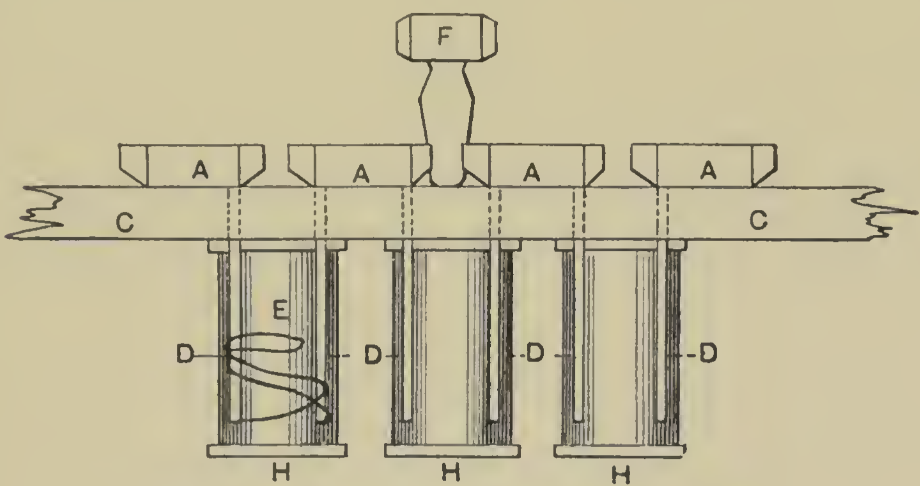

FIG. 62.—CONSTRUCTION OF RESISTANCE COILS.

block in front of the plug, through the plug and the block behind, thus throwing out the coil immediately below the plug ; and that, therefore, the more plugs we introduce, the lower will be the resistance of the circuit ; so, also, if no plugs be introduced, the entire available resistance will be in circuit. By having a sufficient number of such coils, calibrated from 1 ohm upward, we can, by grouping them in boxes, introduce any desired resistance into the circuit. By means of only 16 coils, arranged as shown in figure 63, any number of ohms from 1 to 11,110 may be introduced.

Thus, let us take the circuit shown in diagram in figure 64, consisting of a battery, B, an unknown resistance, R, and a galvanometer, G. The deflection of the galvanometer needle, caused by

the current, is first noted; then the set of known resistances is substituted for R, and resistance coils are thrown out by the insertion of plugs, until the galvanometer needle gives the same deflection as in the first case. The resistance remaining in the circuit will necessarily equal the resistance previously introduced—viz.,

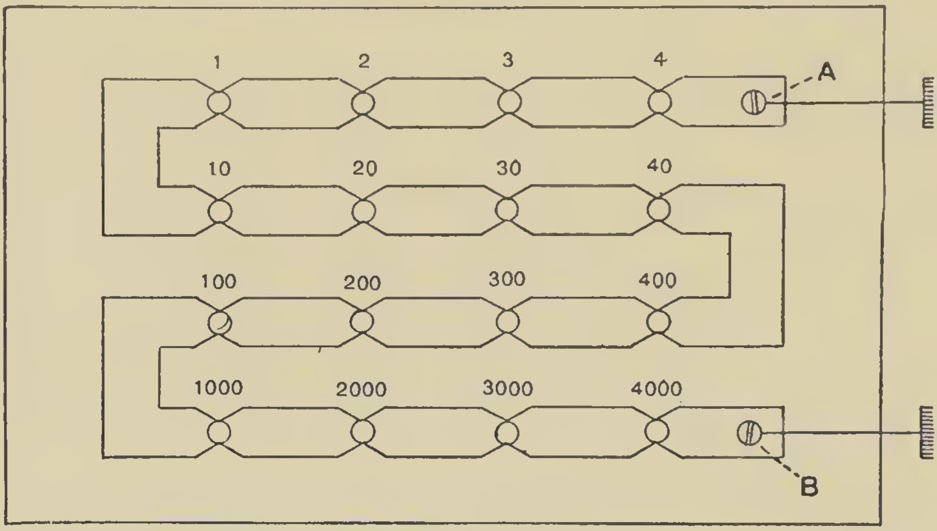

FIG. 63.—ARRANGEMENT OF RESISTANCE COILS.

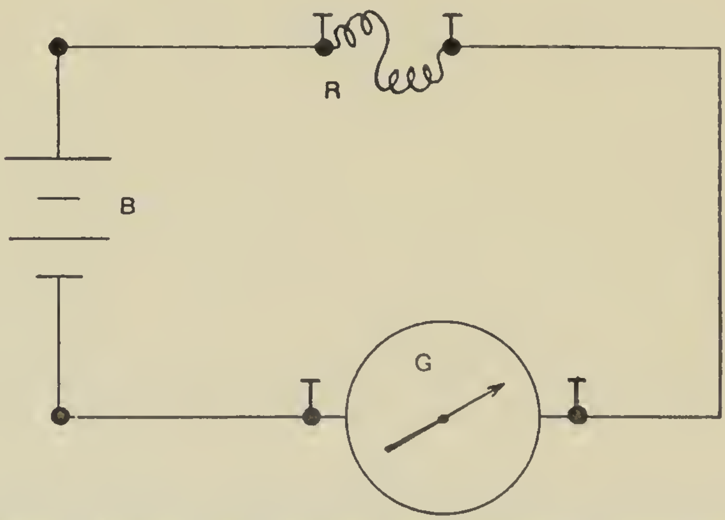

FIG. 64.—SHOWING METHOD OF DETERMINING UNKNOWN RESISTANCES BY SUBSTITUTION.

the unknown quantity; and the reading thus obtained is the measure desired.

If, as may be the case when either a very large resistance or a fraction of an ohm is to be measured, this **substitution method** is impracticable, recourse must be had to the method that forms

the basis of many kinds of resistance boxes—viz., that of the **Wheatstone bridge.**

The law governing the principle of the bridge is: "If a current divides into two branches that are connected by a transverse conducting path, then, if there be no current in the transverse path (bridge), the resistances of the two parts of one branch will be equal to the resistances of the two parts of the other branch."

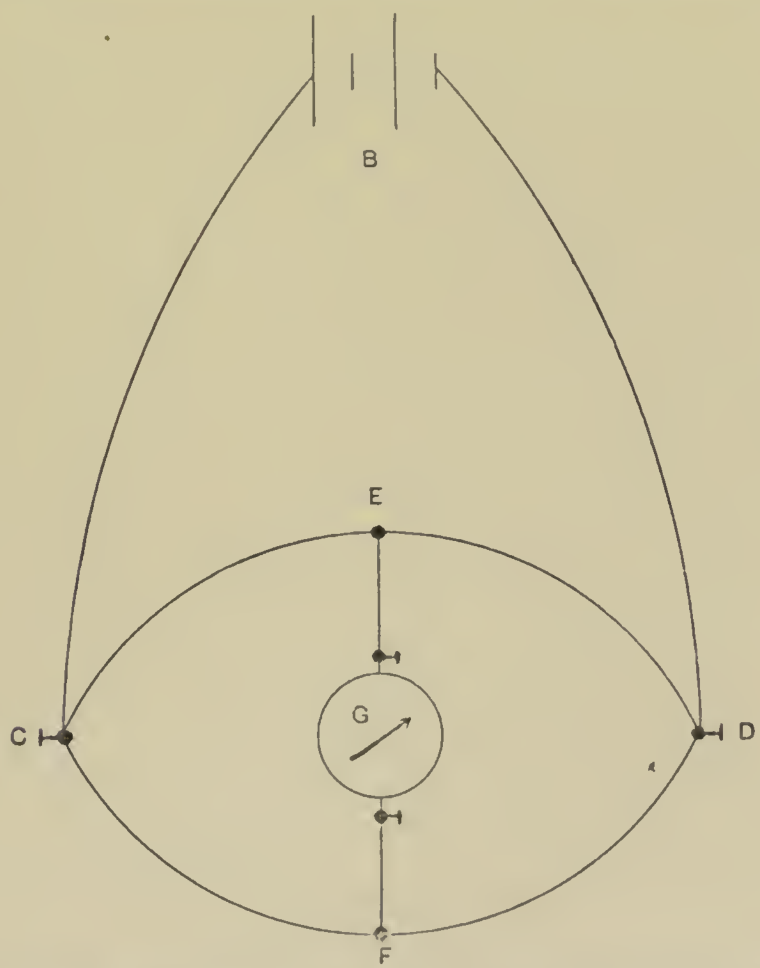

FIG. 65.—SHOWING METHOD OF DETERMINING UNKNOWN RESISTANCES BY THE WHEATSTONE BRIDGE.

Thus if, as is shown in figure 65, in the circuit B C D the current be divided at C D into C E D and C F D, and, furthermore, the points E and F be connected by a conductor (bridge), then a galvanometer introduced in the bridge E F will, if the parts C E and E D be proportional to C F and F D, show no deflection of its needle; because the current flowing above the needle is equal to

the one flowing below, and their actions neutralize each other. If, now, C E be so constructed as to have the same resistance as E D, and variable known resistances be introduced between D and F, while the unknown resistance to be measured is placed between C and F, then, when the resistance introduced into D F equals the unknown resistance in C F, the needle will return to rest at the zero point and the resistance of D F gives the measure desired.

The Wheatstone bridge is, of course, the most convenient instrument with which to measure resistances; but it may occur that the resistance of a wire coil or lamp is wanted, while no Wheatstone bridge is to be had to measure it. Under these circumstances a **simple method,** dependent on Ohm's law, can be employed. The necessary apparatus are the ampèremeter, the voltmeter, and the source of current. It will be remembered from Ohm's law that $R = \frac{E}{C}$. So, if we measure the current before it enters into our

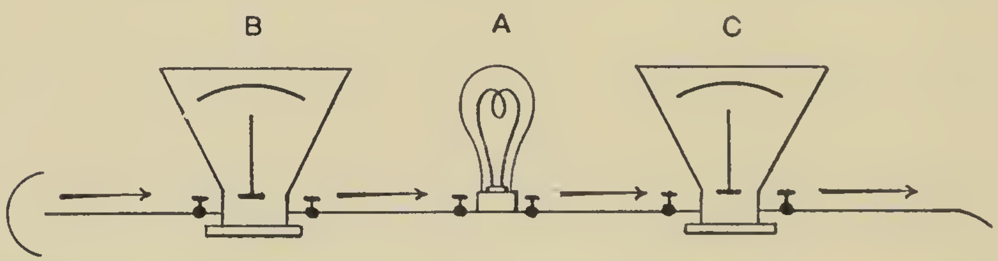

FIG. 66.—SHOWING THE METHOD OF DETERMINING UNKNOWN RESISTANCES BY MEANS OF AN AMMETER AND A VOLTMETER.

unknown resistance and then measure the electromotive force after it has encountered the resistance, we shall have two known quantities for our equation and can easily find the unknown quantity, R. For example, let us find the resistance offered by an incandescent lamp:

In figure 66, A represents the lamp of unknown resistance, introduced into our circuit. The arrows show the direction of the current. Let us introduce an ampèremeter, B, so as to determine our original current before it enters the lamp. In order to determine the electromotive force we insert the voltmeter, C, into the circuit, so as to measure the potential after the current has encountered the resistance. We now take our reading. The ampèremeter registers 0.50, and the voltmeter 109.50. Then, as $R = \frac{E}{C}, \frac{109.50}{0.50}$, 201.90 ohms is the resistance offered by the lamp.

CHAPTER V

OTHER METHODS OF OBTAINING AND ALTERING ELECTROMOTIVE FORCE

Dynamic Induction. Magnetic Induction. Volta-magnetic Induction Apparatus. Dynamos. Thermo-electricity. Thermopile. Sinusoidal Current.

Induction.

Of static induction we have already spoken, but the induction produced by means of d y n a m i c and m a g n e t i c effects is governed by entirely different laws.

In 1831 Faraday discovered that a wire traversed by a current, and suddenly brought near to another wire through which no current is passing, develops in the second wire an instantaneous current of electricity. If the wires, instead of being suddenly approximated, are suddenly separated, the same thing will occur. As it is the approach or the withdrawal of the electric current in the first wire that sets up the momentary current in the second wire, we can more conveniently demonstrate this action by introducing or removing an electric current into or from the first wire. This will be made plain by the following illustration (Fig. 67).

Let A represent a galvanic current supplied by the current from a battery, B, and having at some part a switch, S, that will enable us to introduce and throw out the current; and let C represent a similar wire circuit placed parallel to A, and in which is placed a galvanometer, G. If the switch at S be closed, a current will flow through A in the direction indicated by the arrows. At the moment the circuit in A is thus closed, the galvanometer needle, which, while at rest, occupied the north-south position, will be deflected. This deflection will be to the west—that is, the north pole of the needle will be turned to the west; but it will return immediately to its north-south position, retaining this while the current continues to flow through A. At the moment the circuit is again broken at S the needle will again be deflected, but this time in the opposite

direction, with its north pole to the east. Therefore a reverse current is produced in B at the moment the circuit is closed in A, and at the moment the current is broken in A a current will be generated in B whose direction is the same as the one that had existed in A.

This production of momentary currents in a closed electric conductor, by making and breaking a current in an adjoining galvanic circuit, is called **electrodynamic** or **voltaic induction.** The

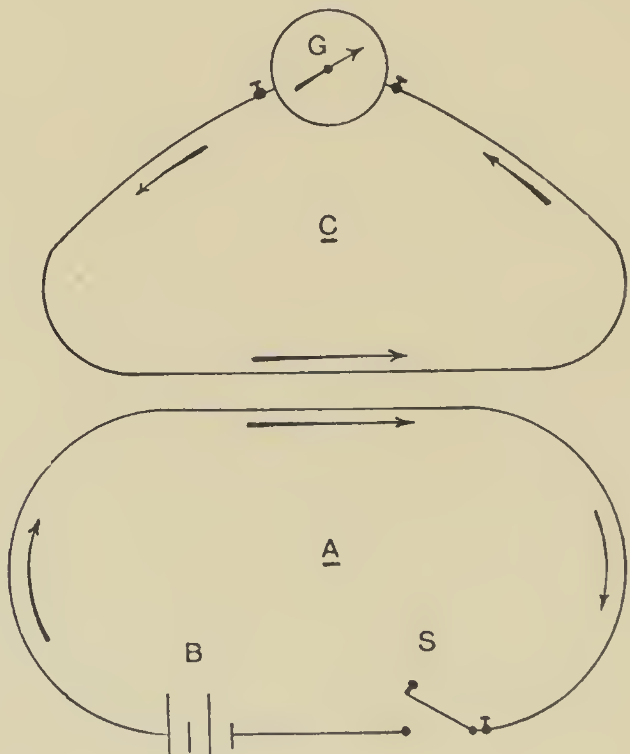

Fig. 67.—Showing the Method of Producing an Induced Current.

galvanic current circulating in A is called the primary current; the current that is set up in B, and whose direction is opposite to the primary one, is called the closure induction current; while the current of similar direction to the primary one is called the opening induction current. Increasing or decreasing the current strength in A will produce in B the same effects as closing and opening the A circuit. If, furthermore, instead of making use of an inducing galvanic current for the production of such momentary induced currents we make use of a

magnet, approaching and withdrawing it suddenly from B, the same results would be obtained—viz., the production in B of currents of opposite directions to each other. So, also, the same effects may be produced by the magnetization or demagnetization of an iron core of an electromagnet, as well as by increasing or decreasing the quantity of such magnetism.

This production of momentary electric currents in a closed electric conductor by means of the approach or withdrawal of adjoining magnets, or by the magnetization or demagnetization of the core of an adjoining electromagnet, is called **magneto-induction.**

In order to produce an intensification of energy, the wire A may

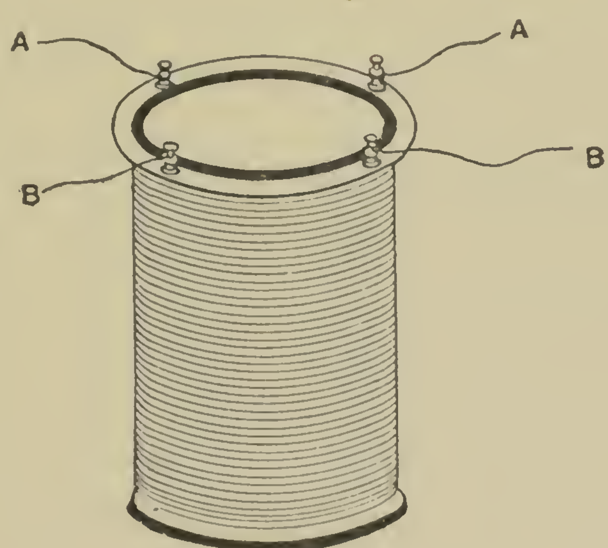

FIG. 68.—AN INDUCTION COIL.

be wound around a nonconducting cylinder; the wire itself being covered with silk, each turn of the spiral is insulated from the adjoining turn. Over this wire the second wire, B, also covered with silk, is wound (Fig. 68).

The cylinder so wound with wire is called an **induction coil**; the wire A, which is first wound round the cylinder and in whose circuit the current is made and broken, is the *inducing wire*; the wire B, in which the momentary currents are set up and from which they are collected for use, is called the *induced wire*. The inducing wire and the induced wire may each be wound upon a separate nonconducting cylinder, the one being sufficiently small to allow

of its introduction into the other ; we then have a model according to which the sled induction apparatus is constructed. Herewith the strength of the secondary current may be varied, for if the secondary coil cover the primary coil to its full extent, the number of turns of wire in which induction takes place will be greater, and hence the current stronger, than if only a part of the primary coil be so covered by the secondary one. It will thus be seen that by increasing the number of turns in the coils we also increase the strength of the secondary currents. Another method by which induced currents may be increased in strength is the ingenious combination, already known to Faraday, of magneto- and volta-induction. This combination Faraday effected by introducing a core of soft iron into the primary spiral. Upon the closure of the galvanic current this iron core becomes an electromagnet, but upon the opening of the current the magnetism disappears ; and thus the production and withdrawal of magnetism in the iron core act inducingly upon the secondary coil, in the same manner as do the closure and opening of the current, so that the influence of the primary coil becomes summated, the volta-induction currents acting together with the magneto-induction ones.

The action of induction previously described as taking place between adjoining parallel wires must, of course, also take place between the adjoining wires of the primary coil, and this fact explains the observation made by others, but correctly interpreted by Faraday, that when a current that is flowing through a long wire spiral is interrupted, an opening spark is obtained that is stronger than the opening spark obtained from the source of the induction itself, and that, furthermore, the longer the wire of the spiral, the stronger is the opening spark. The explanation of these phenomena is that the cessation of the current in one turn of the spiral produces a similarly directed momentary current in the adjoining turn ; these currents between the single turns become added to each other, and produce the opening induction spark, which necessarily is the greater, the more numerous the turns of wire that make up the spiral. This induction action takes place not only with the opening, but also with the closure, of the current, when this induction current that arises in the primary coil is known as the extra current,

or primary induced current, in contradistinction to the secondary induced current produced in the secondary coil.

The construction of an apparatus for the production of a volta-induced current can easily be deduced from the foregoing description of the principles underlying the sled apparatus, except that in addition to a source of galvanic current, a primary coil with a core of soft iron, and a secondary movable coil, some mechanism by means of which the electric current can rapidly be made and broken must be employed. More will be said in reference hereto when we describe apparatus of an essentially medical nature. Here

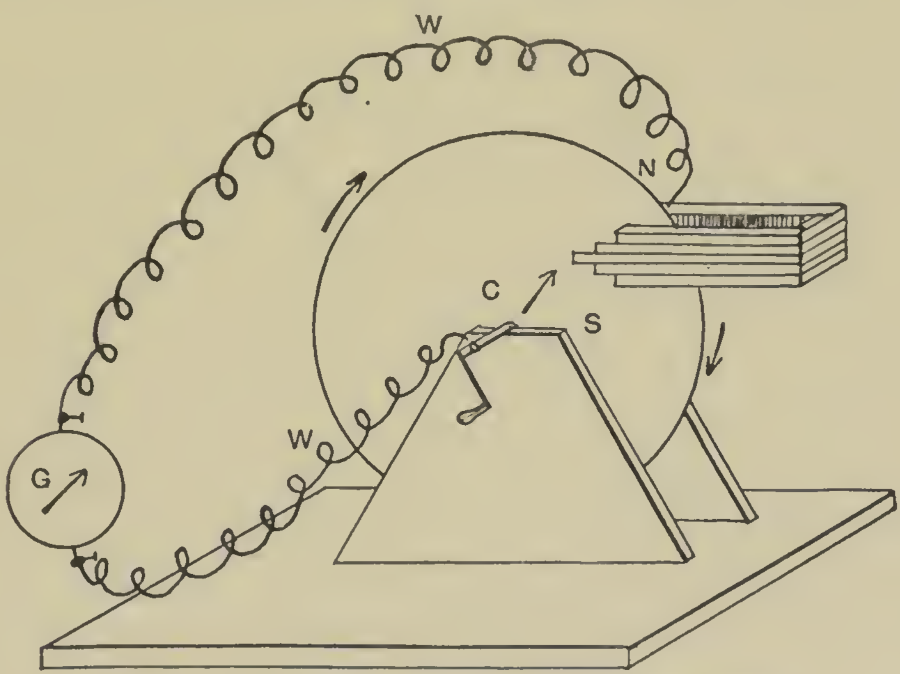

FIG. 69.—FARADAY'S MAGNETO-ELECTRIC MACHINE.

it is, nevertheless, still necessary to speak of the principles that underly the construction of a magneto-induction apparatus. The essentials of such an apparatus are:

1. A magnetic source (a permanent or an electromagnet).
2. The induction spirals.
3. A mechanism by which the induction spirals may be approached to and withdrawn from the magnetic source, or by which the latter may be approached to or withdrawn from the former.
4. A mechanism for the collection of the induced currents thus produced.

The approach and separation of the magnet and coil may be effected by rotating the induction spirals in front, above, below, or between the poles of a horseshoe magnet, or by rotating such a magnet in front, above, below, or around the induction spirals. The induction spirals may be variedly constructed.

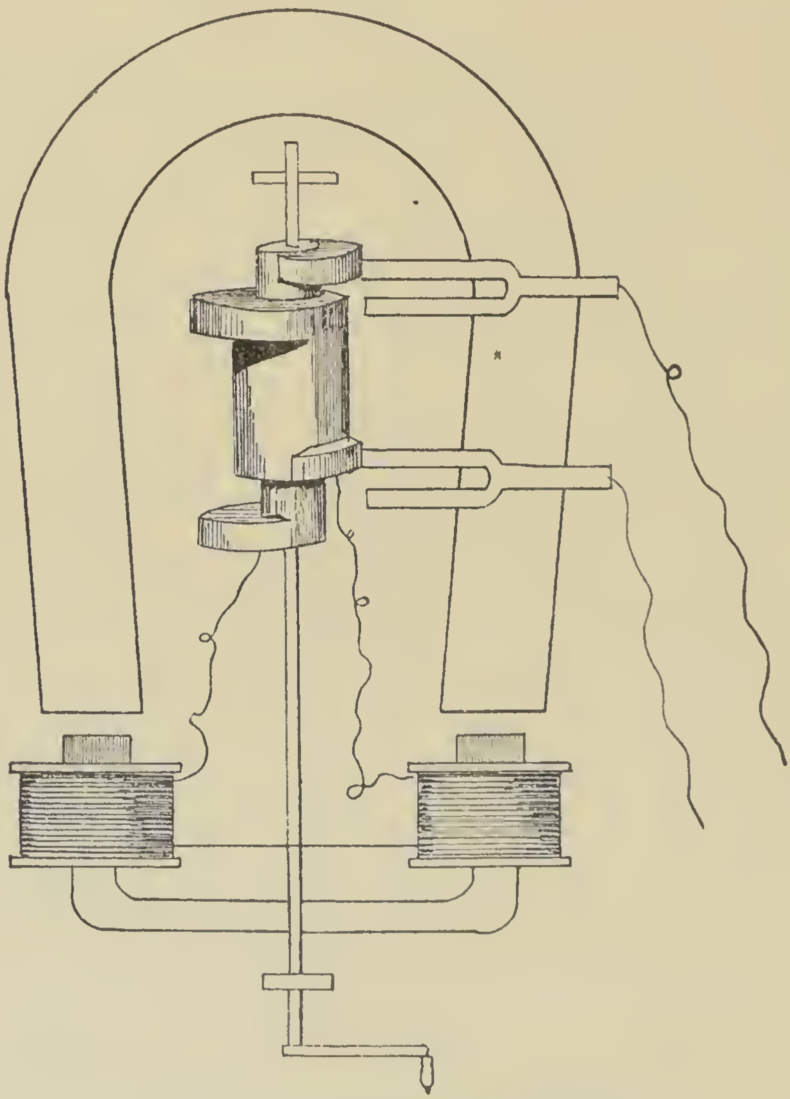

FIG. 70.—THE HORSESHOE INDUCTOR.

The earliest and simplest magneto-electric machine was constructed by Faraday. This machine is shown in figure 69.

One of the oldest forms is the horseshoe inductor, in which the induction coils are placed so as to surround the ends of a core of soft iron bent in the shape of a horseshoe, as shown in figure 70. This inductor is made to rotate below, behind, or in front of the poles

of the permanent magnet. Another form of inductor is made of a cylindric iron core having a deep groove upon two opposite surfaces, in which the wire of an induction spiral is so wound that the turns run along the cylinder lengthwise, from the groove of the one surface to the groove of the other. This cylindric inductor is made to rotate between the poles of the horseshoe magnet in such a manner that its axis is parallel to the arms of the magnet. Of entirely different construction is the Gramme ring inductor.

For gathering the current either a collector or a commutator is made use of; in the first case only alternating currents are obtained; in the second, unidirectional ones.

Without entering here upon a detailed description of such machines, it may be stated that the industrial machines for furnishing current for technical purposes are, with more or less complication, constructed essentially upon such a plan.

The modern **dynamo** is an apparatus that is unsurpassed for simplicity of construction and efficiency in transforming one kind of energy into another. The dynamo is actually a reversible machine, which either transforms mechanical energy into electric energy, as is the case in the magneto-machine just spoken of, or it transforms electric energy into mechanical energy. In the first case it is called a dynamo; in the second, a motor.

The simplest form of dynamo necessarily gives an alternating current and is called an alternator. When supplied with the piece of apparatus called the commutator, the current in the practical (external) circuit is constant in one direction. To such a direct current machine the term dynamo is restricted by many.

Currents from such machines are now supplied from central stations for illuminating purposes, and are available in most houses of large cities. Special consideration will be given in another chapter to the adaptability of these currents for medical purposes.

Thermo-electricity.

A source of electricity that has hitherto been impracticable and that seems now to promise a satisfactory current supply for many medical purposes is the thermo-electric element.

A polished copper wire bent in the shape of a ring, the two ends being connected with a delicate galvanometer, will, if heated at any part, cause a deflection of the needle, thus showing that the application of heat has produced a current of electricity in the ring. If such a ring be made of two different metals, by soldering them together lengthwise the deflection of the needle will be greater than if the ring be made of copper alone.

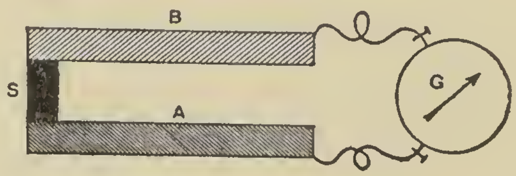

FIG. 71.—THERMO-ELECTRIC COUPLE.

If a bar of bismuth, B (Fig. 71), and a bar of antimony, A, be soldered together at one end, S, and the free ends are joined by a wire, a current of electricity will flow through the wire when the solder is heated; if the solder be cooled, a current of opposite direction will be created. A number of such couples or elements (Fig. 72) may be joined together so that a bar of antimony alternates with a

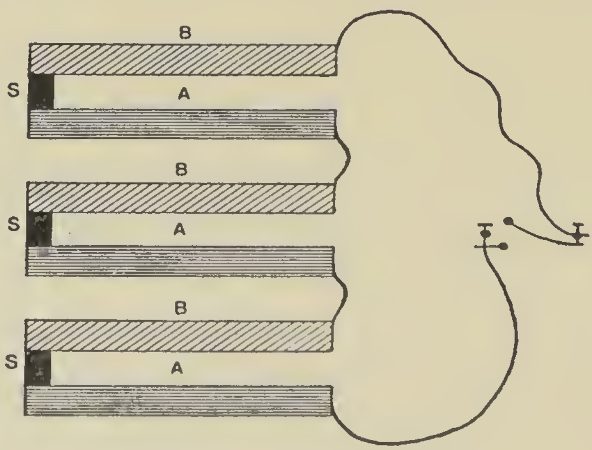

FIG. 72.—THERMOPILE.

bar of bismuth. The intensity of the current is thereby increased, a smaller quantity of heat causing deflection of the needle of a galvanometer in circuit. Such an arrangement is called a **thermopile**, or t h e r m o - e l e c t r i c b a t t e r y, and the current derived therefrom is termed **thermo-electricity**.

Experiments made with various combinations of metals show that the different metals may be arranged into an electromotive series that is governed by the same laws as those that govern a voltaic series. This series is: Antimony, iron, zinc, silver, gold, tin, lead, mercury, copper, platinum, and bismuth. The antimony forms the positive, and the bismuth the negative, end of the series. In a thermocouple of antimony and bismuth, which gives the greatest difference of potential and therefore, other things being equal, the greatest electromotive force, the current produced by heating the soldered place flows from the bismuth to the anti-

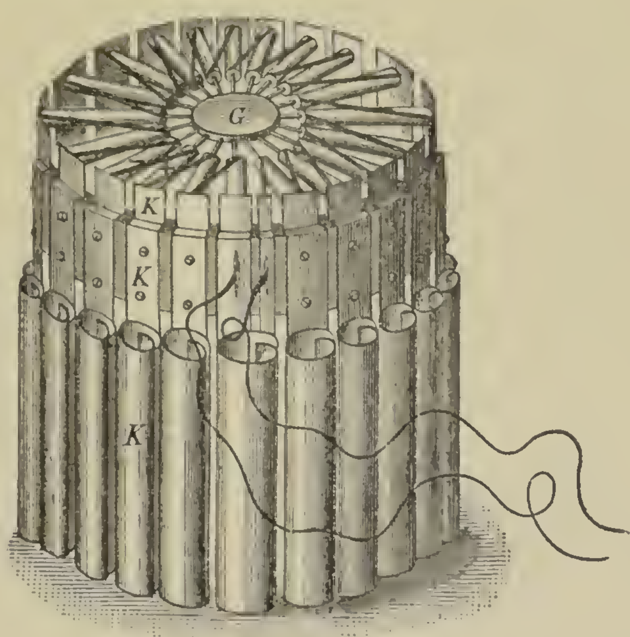

FIG. 73.—THE NOÊ THERMOPILE.

mony; that caused by cooling the solder flows from the antimony to the bismuth.

The intensity of the thermocurrent is dependent, aside from the specific constituents of the source, mainly upon the differences in temperature of the two soldered ends, but also in part upon the absolute temperature of the two metals. Therefore the higher the heat in the metals, and yet the greater their difference of temperature, the stronger will be the current obtained.

A practical form of thermobattery, one that has been widely copied and modified, is that constructed by F. Noë, of Vienna, and

known as the Noë thermopile. This pile is shown in figure 73. The source of heat is a Bunsen flame. Such a battery of thirty couples possesses an internal resistance of 0.4 ohm, and an electromotive force of about 2 volts; thus, short circuited, it would furnish a current of 5 ampères.

Sinusoidal Current.

A great deal of attention has of recent years been given to the use of the sinusoidal current in electrotherapy, and as this current is a form of the induced current that we have just studied, it will not be amiss to speak of it here.

A **sinusoidal current** is an alternating induced current in which the electromotive force is so varied that its rise and fall in a positive direction are immediately succeeded without a break by an exactly corresponding fall and rise in the negative direction, and this rise and fall in both directions would, if graphically illustrated, describe a sine curve. This will be better understood by reference to the pages that follow and that deal with the varieties of electromotive force.

CHAPTER VI

VARIETIES OF ELECTROMOTIVE FORCE

Continuous. Alternating. Pulsating. Steady. Symmetric. Dissymmetric. Intermittent. Nonintermittent. Sinusoidal. Nonsinusoidal. High Frequency.

Inasmuch as there is but one electricity and the action of electricity upon organic and inorganic substances varies according to the source from which the electricity is obtained, it is necessary to inquire into the causes of such variation.

These causes are dependent, first, upon the variations in the electromotive force, which sets the electricity into action, upon its duration, and upon its direction; and, secondly, upon the other factors governing the flow of current, quantity, and resistance. An examination of the variations in duration and direction of the electromotive force produced will make clear the characteristics of the different currents.

These currents, following Houston and Kennelly, are:

- CURRENTS
  - CONTINUOUS
    - Pulsating
      - Intermittent.
      - Nonintermittent.
    - Steady.
  - ALTERNATING
    - Symmetric
      - Sinusoidal.
      - Nonsinusoidal.
    - Dissymmetric.

Houston and Kennelly's description is as follows:

Varieties of Electromotive Force.

The voltaic or primary cell and the storage or secondary cell will produce an electromotive force that, so long as the chemicals remain unchanged, does not vary in strength. Such an electromotive force is, therefore, called a **continuous electromotive force.**

A continuous electromotive force is also obtained from a number

of other electric sources, such, for example, as a continuous current dynamo, which, so long as its speed of rotation remains the same, produces an electromotive force that is practically continuous. Figure 74 represents graphically a continuous electromotive force. The straight line A–S is drawn parallel to the base line 0–S, at a distance representing 1.1 volts. Time is measured along the base line 0–S, and the fact that the line A–S runs parallel to the base line illustrates the constancy of the electromotive force, which might be that of a single Daniell cell. Two such cells connected in series would produce an electromotive force of 2.2 volts, represented by the straight line C–D, twice as far above the base line as is the line A–S.

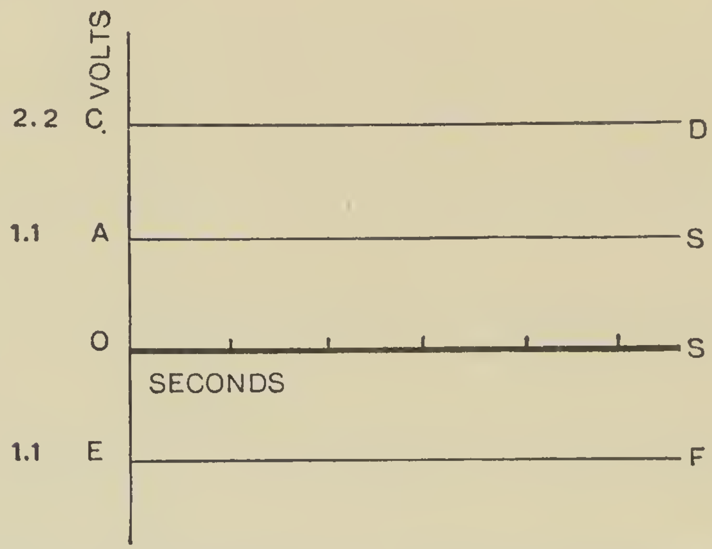

FIG. 74.—GRAPHIC REPRESENTATION OF A CONTINUOUS ELECTROMOTIVE FORCE.

An electromotive force possesses direction as well as magnitude; that is to say, it may tend to send a current through a circuit in one direction or in the opposite direction. All electromotive forces that tend to send the current in one direction may be regarded as positive, and all that tend to send the current in the opposite direction as negative.

Positive electromotive forces are represented graphically by distances above the line 0–S, and negative electromotive forces by distances below it. Thus, in figure 74 the line E–F would indicate a negative electromotive force of 1.1 volts, or an electromotive force directly opposed to that of the line A–S. Figure 75 shows the

electromotive force produced by a continuous current dynamo. Here the line A–B is parallel to the base, as before, but instead of being straight, is a fine wavy line. These little waves represent

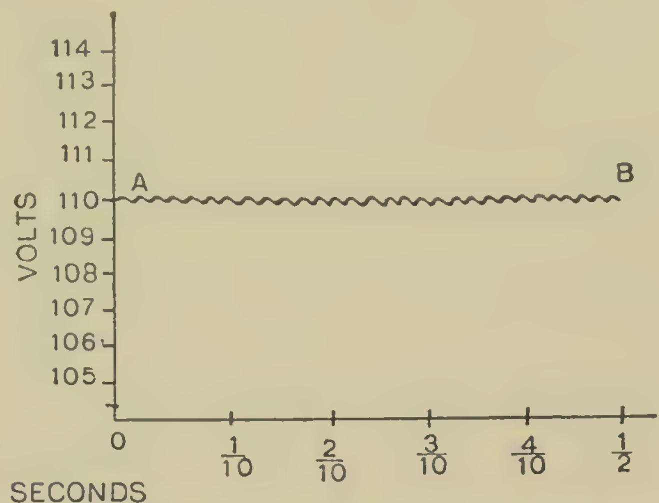

FIG. 75.—GRAPHIC REPRESENTATION OF THE ELECTROMOTIVE FORCE PRODUCED BY A CONTINUOUS CURRENT DYNAMO.

variations in the quantity of electromotive force produced every time that the bar of the commutator passes underneath the electric brush. These wavelets exist in the electromotive force of every con-

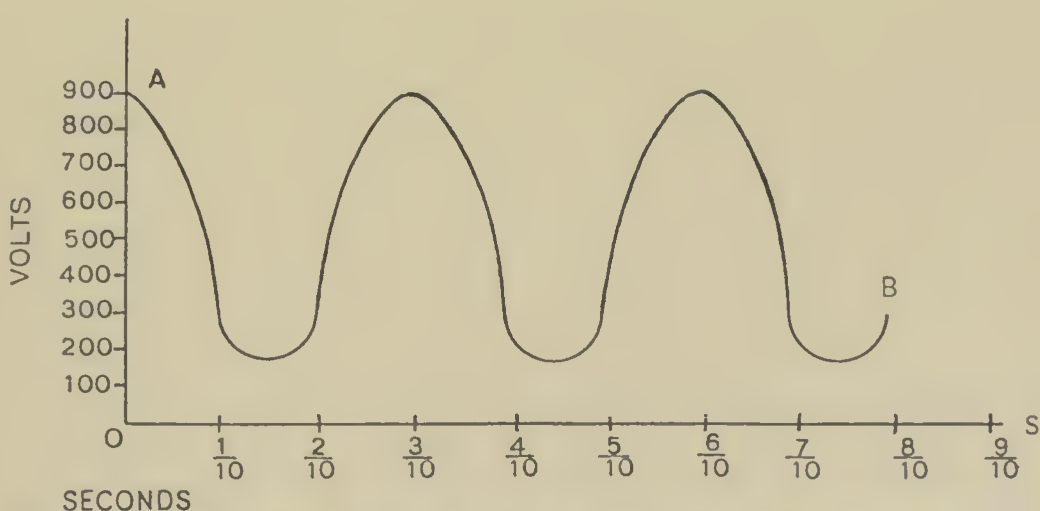

FIG. 76.—GRAPHIC REPRESENTATION OF A PULSATORY ELECTROMOTIVE FORCE.

tinuous current dynamo. When they are very marked, as represented in figure 76, the electromotive force is said to be **pulsatory**. Such electromotive forces are produced by some continuous current

generators, usually for supplying arc lamps. It is evident that at different times the electromotive force varies considerably in its magnitude, but it never changes direction, and the line A–B is always on one side of the zero line O–S; that is to say, it has always the same direction in the circuit, just as though a battery of voltaic cells were employed to send a current through a circuit, and at intervals a certain number of these cells were cut out and later reintroduced.

When the waves start each time from the zero line, the electromotive force is said to be **intermittent.** Figure 77 shows that, at certain periods, an electromotive force exists in the circuit in

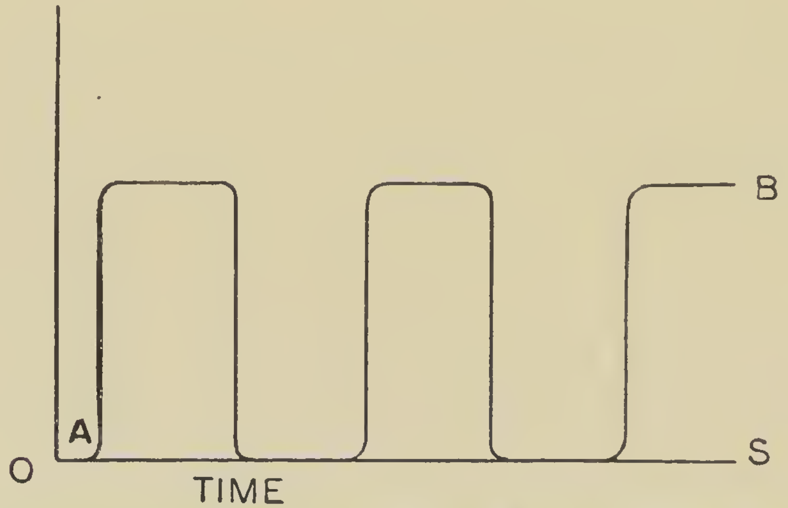

FIG. 77.—GRAPHIC REPRESENTATION OF AN INTERMITTENT ELECTROMOTIVE FORCE.

one direction, and that during the intervals there is no electromotive force whatsoever. The intermittent electromotive force can be obtained by connecting a continuous electromotive source—*e. g.*, a voltaic battery—to a wheel interrupter in such a manner that the electromotive force will periodically be cut off and applied.

In all the foregoing cases, although the strength of the electromotive force varies at different times, yet at no time does it change direction, so that the curved line lies wholly above the base line.

When the electromotive force changes direction as well as magnitude, it becomes **alternating.** Thus, in figure 78 the electromotive force is seen to alternate between 10 volts positive and 10 volts negative, the transitions in this particular case being made

instantaneously. Such an electromotive force may be produced by connecting a battery of voltaic cells with a current reverser in such a manner that, by rotating the handle, the electromotive force

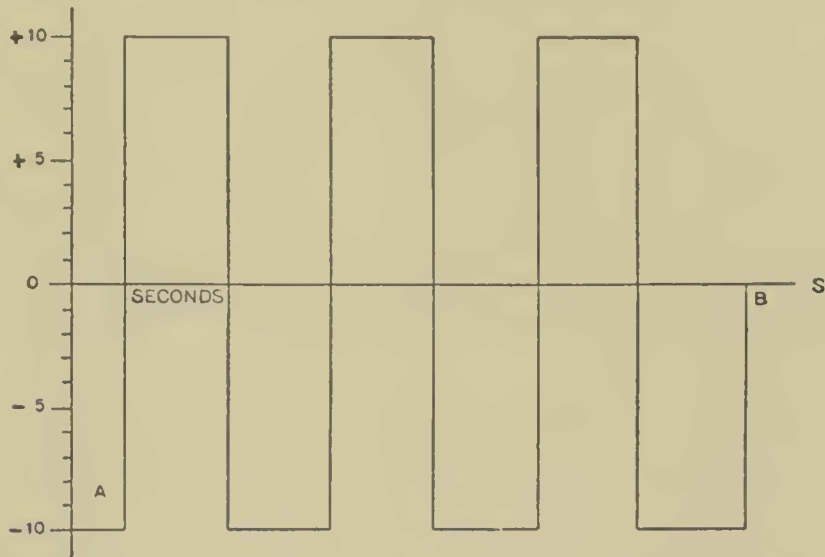

FIG. 78.—GRAPHIC REPRESENTATION OF AN ALTERNATING ELECTROMOTIVE FORCE.

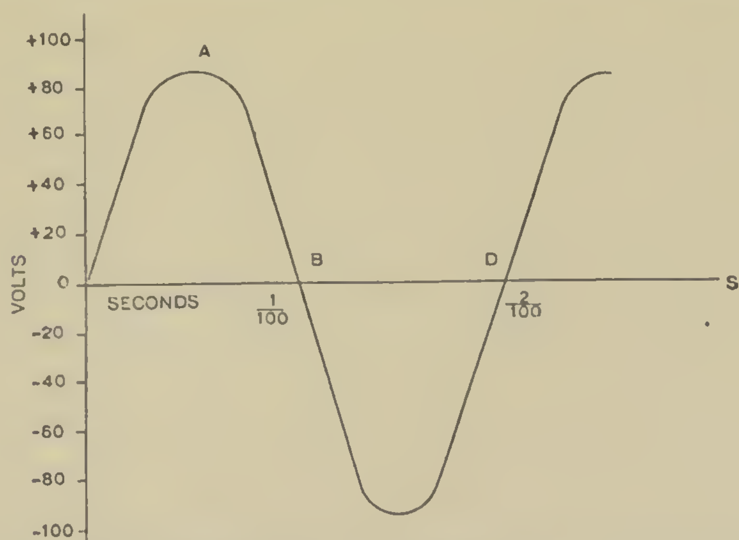

FIG. 79.—GRAPHIC REPRESENTATION OF A GRADUALLY ALTERNATING ELECTROMOTIVE FORCE.

will periodically be reversed without being withdrawn from the circuit.

It is not necessary that an alternating electromotive force should change abruptly from its maximum positive to its maximum negative value. In fact, in most cases the change occurs in a more

gradual way, as shown in figure 79, which illustrates a common type of alternating electromotive force.

Figures 80 and 81 represent the same alternating electromotive

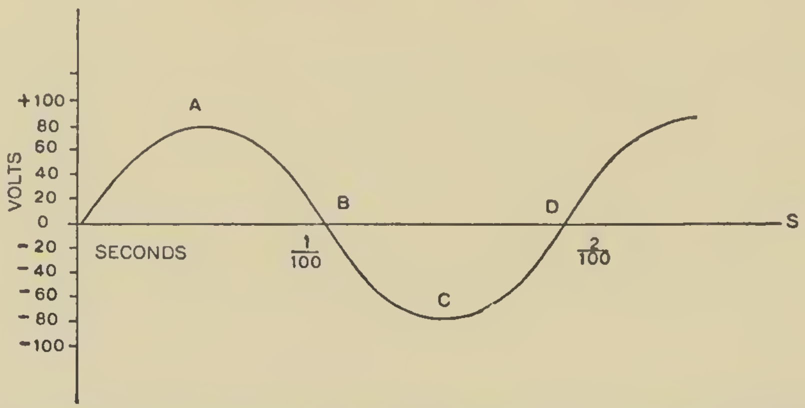

Fig. 80.—Graphic Representation of a Gradually Alternating Electromotive Force.

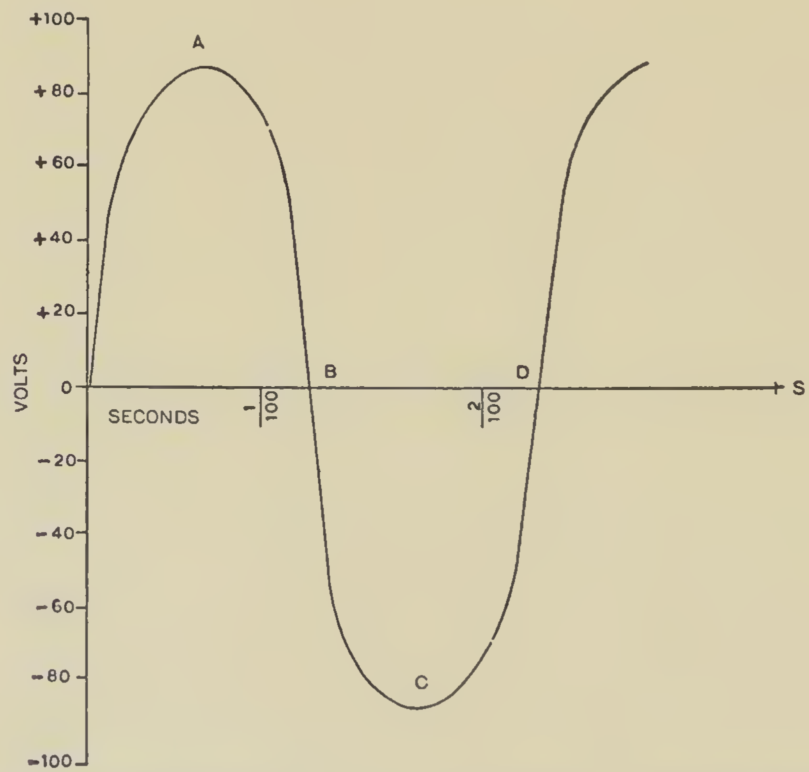

Fig. 81.—Graphic Representation of a Gradually Alternating Electromotive Force.

force, although the graphic appearance of the waves is changed, owing to the variations of the scale of time along the base and of the scale of electromotive force along the vertical line.

It will be observed that in all representations of alternating electromotive force there is first motion in one direction, in which the electromotive force beginning at the base line, or zero, gradually increases in value to a maximum, and then gradually falls until it again reaches zero; then changes direction, going through a like rise and fall in the opposite phase. Each of the waves O A B or B C D is called an alternation.

Alternating electromotive forces may be **symmetric** or **dissymmetric.**

A **symmetric electromotive force** (Fig. 82) is one in which

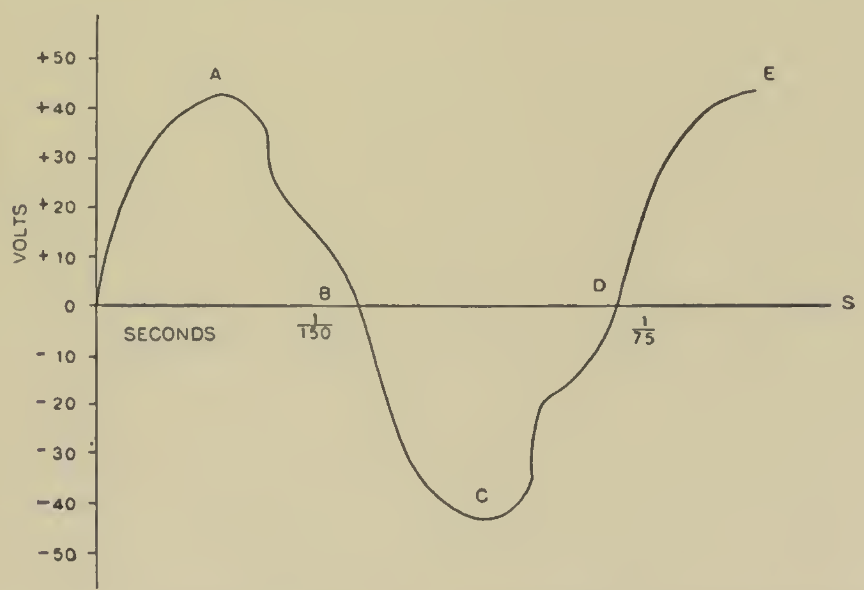

FIG. 82.—GRAPHIC REPRESENTATION OF A SYMMETRIC ELECTROMOTIVE FORCE.

the positive waves are the same as the negative waves, except that they move in opposite directions.

A **dissymmetric alternating electromotive force** (Fig. 83) is one in which the positive wave differs from the negative, not merely in its direction, but also in its outline.

Symmetric alternating waves of electromotive force are produced by alternating current dynamos, or alternators. **Dissymmetric** alternating electromotive force waves are produced by particular types of apparatus, such as faradaic coils.

It is clear that an electromotive force is alternating if it changes its direction and magnitude periodically, and that considerable varia-

tion may exist in the manner in which both of these changes may occur.

A wave of the form shown in figure 84 is called a *sinusoidal*

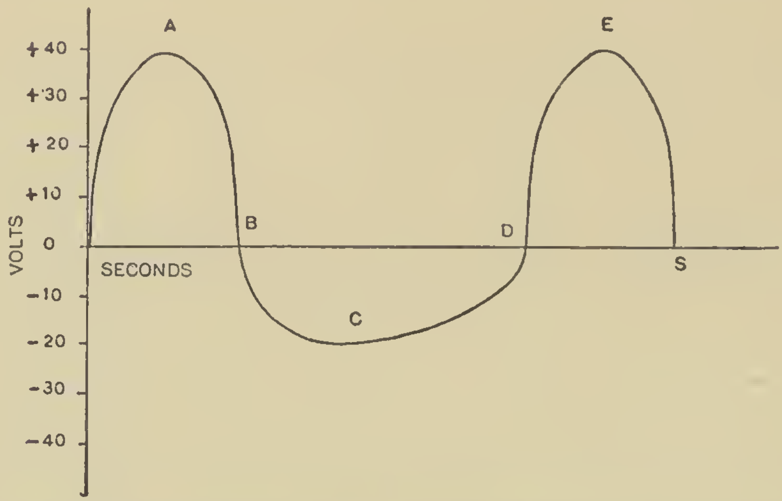

FIG. 83.—GRAPHIC REPRESENTATION OF A DISSYMMETRIC ELECTROMOTIVE FORCE.

wave, and an electromotive force alternating in this manner is called a **sinusoidal electromotive force.**

The electromotive forces produced by *friction* are much higher than those produced by voltaic cells or dynamo-electric machines. The electromotive force produced by a properly operated friction

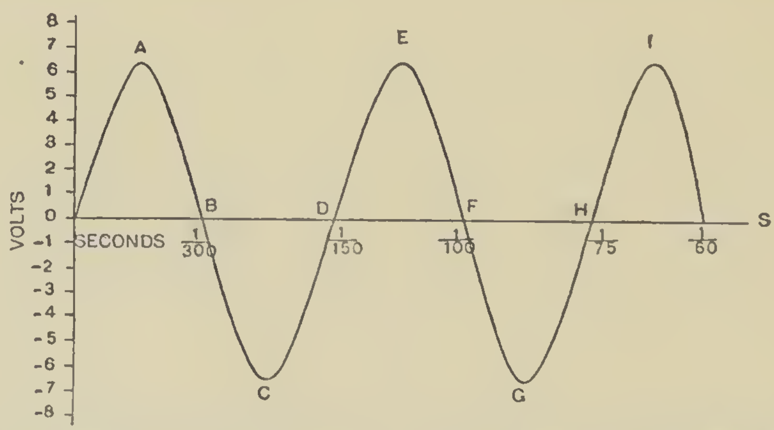

FIG. 84.—GRAPHIC REPRESENTATION OF A SINUSOIDAL ELECTROMOTIVE FORCE.

machine is of the **pulsatory** character. When a pulsatory electromotive force attains a strength sufficient to discharge itself through an air gap, it suddenly falls to a minimum. It then recovers and again discharges, and this action is carried on in a pulsatory manner

at frequent intervals. Such a pulsatory electromotive force is shown in figure 85.

Currents of High Frequency.

Some consideration must be given to a manifestation of the electric energy that has occupied the attention of students during the last years, and whose introduction into electrotherapeutics has greatly enlarged the scope of this branch of medicine. We refer to currents of **high frequency.** As all electric sources produce electromotive forces, so do all electromotive forces under suitable conditions produce currents or discharges. The character of the current

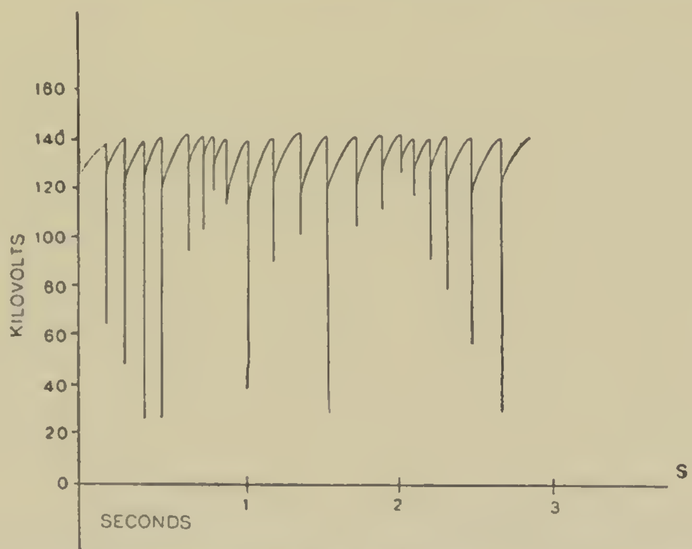

FIG. 85.—GRAPHIC REPRESENTATION OF A PULSATORY ELECTROMOTIVE FORCE.

or discharge is dependent upon the character of the electromotive force that produces it, so that no matter how a discharge may differ in appearance from some other discharge, this difference is entirely dependent upon the character—*i. e.*, the frequency, the magnitude, and the wave type—of its electromotive force.

When a ball prime conductor of a **static machine** is made to discharge the electricity with which it has been charged, it does so in a disruptive manner or as a s p a r k. This seems to consist of a number of separate discharges, to and fro, between the ball and the object into which it discharges. The discharge is an o s c i l l a t o r y one. When a condenser, as a ball prime conductor, charged to a very high potential, is discharged into a conductor having

a certain self-induction and slight resistance, extremely rapid, isochronous oscillations are produced, that constitute a **high frequency current.**

The frequency of oscillations is often exceedingly high, reaching at times hundreds of millions of cycles in a second (experiments of Herz). The total number of oscillations in one discharge is, however, not very great. When we consider that the greatest number of vibrations that can be appreciated in the production of sound is 36,000 in a second, we must admit that the term "high frequency," as applied to the electric oscillations, is well merited.

The following mechanical effects will clearly explain the phenomenon. If a vibrating straight spring be firmly fixed at one end, and the free end be moved from its vertical position of equilibrium and then again liberated, the spring will oscillate for a certain period of time before it regains its former position of equilibrium, providing that the surrounding medium is one of slight resistance, such as air, alcohol, or water. If, on the other hand, this medium be a liquid of very great density, as oil, there will be no oscillation, but an aperiodic return to the vertical position.

Again, if in a U-tube partially filled with fluid a change of level be produced by pressure upon one limb, and this pressure be suddenly removed, the fluid will at once move in both branches in order to re-establish an equilibrium, and if the resistance to its rise and fall be slight, it will oscillate for a certain time before coming to rest at the same level in the two limbs; if, on the other hand, there be a marked resistance to this movement of fluid, the level will become re-established in an aperiodic manner. (See Figs. 86 and 87.)

In both of these examples we have slow cycles of visible movement. In both we have a dissipation of energy, manifesting itself in the form of heat, equal to the work necessary for the production of the primary deflection from the position of rest.

In the currents of high frequency we have, as stated, rapid cycles, with invisible movement and a dissipation of energy, in the form of emitted radiations, whose existence can be proved by the aid of a mobile conductor passed in the neighborhood of the circuit of high frequency. As the frequency of oscillation of the spring

will depend upon the elasticity of the spring, upon the strength of fixation, and upon the resistance of the surrounding medium, so an electric circuit in which a discharge suddenly takes place will follow precisely parallel laws. The resistance of the medium corresponds to the resistance of the electric circuit in ohms. The elasticity of the spring corresponds to the electrostatic capacity of the circuit or to its capacity as a condenser, and the fixation of the spring corresponds to the inductance of the circuit.

Therefore when a discharge is effected into an electric circuit, this discharge will be oscillatory or nonoscillatory, in accordance

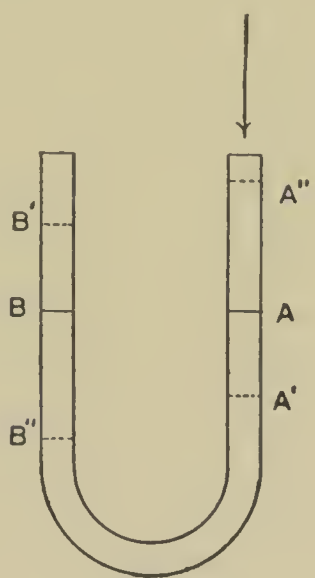

Fig. 86.

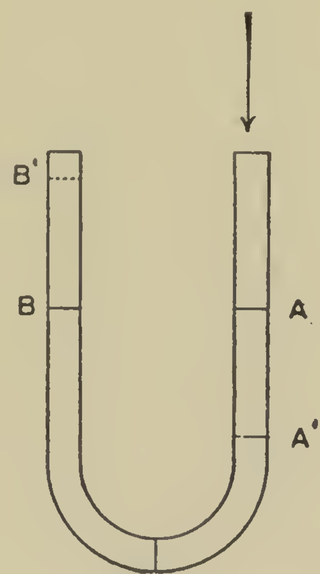

Fig. 87.

Figs. 86 and 87.—Showing the Oscillations of a Liquid in the Limbs of a U-Tube.

with the degree of resistance of the circuit as compared with its capacity and inductance, and the oscillations will be more powerful the higher the electromotive force employed to produce the waves. Thus, the high electromotive force obtained from an influence machine will give very powerful oscillations.

In electrotherapeutics W. J. Morton, of New York, many years ago introduced the use of such discharges under the misleading name of "static induced currents." These electric phenomena have been well known for many years, and so far back as 1855 Sir William Thompson gave the theory of their causation. Neverthe-

less, it was not until Herz began his series of remarkable experiments that the electric oscillations became the object of great interest. Herz showed that these oscillations could be maintained by means of an induction coil, and that their electric effects were propagated to a distance in the same manner as light. One of the arrangements by which Herz made his studies is shown schematically in figure 88.

I is an induction coil; C and D are two balls 15 centimeters in diameter, serving as condensers, and attached to two small balls, A, B, acting as dischargers, by two cylindric rods, each 5 millimeters in diameter and 1 ½ meters in length. The spark produced between

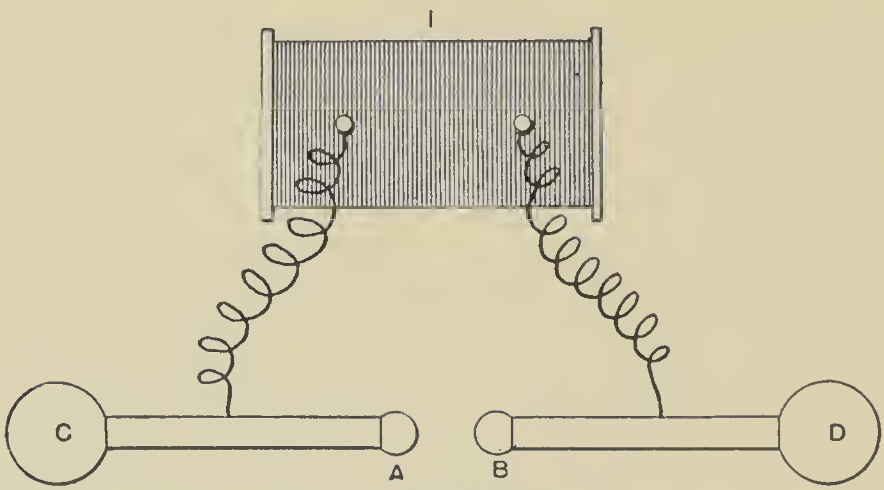

FIG. 88.—SCHEME OF HERZ'S INDUCTION COIL FOR PRODUCING HIGH FREQUENCY OSCILLATIONS.

A and B was one of about 15 millimeters. On account of the smallness of condenser capacity and of conductors, the frequency of oscillations obtained reached 100,000,000 in a second.

Tesla later made use of two procedures in order to produce the high frequency currents. In the first method he made use of alternators with very many poles, and by means of transformers raised the potential to tens of thousands of volts; in a second method he used a modified Herz apparatus.

Elihu Thomson has since then considerably modified and increased the efficiency of the necessary apparatus.

Part II

APPARATUS REQUIRED FOR THE THERAPEUTIC AND DIAGNOSTIC USE OF ELECTRICITY

PART II

APPARATUS REQUIRED FOR THE THERAPEUTIC AND DIAGNOSTIC USE OF ELECTRICITY

ITS SELECTION MODE OF APPLICATION AND CARE

PRELIMINARY

The **electric apparatus** used in medicine are, as may be deduced from the preceding chapters, of four different kinds:

1. Instruments supplying **static electricity**;
2. Instruments supplying **dynamic electricity**;
3. Instruments supplying **induced electricity**;
4. Instruments that **change the character of the electromotive force** derived from one of the foregoing.

The number of apparatus employed for these varied purposes is so great that it is impossible to describe them all. Such description, moreover, is unnecessary, inasmuch as the principles governing the construction of each class are the same throughout. These principles have been sufficiently elucidated to enable us to select single pieces of apparatus as examples of each class, and to make their descriptions comparatively brief. We must also consider apparatus **rendering the physical effects of the electric current available** for treatment and diagnosis. Hereunder we include **electrocautery, electric light,** and the **Röntgen rays.**

CHAPTER I

FRICTIONAL ELECTRIC APPARATUS AND ITS USE

Influence Machine. Charge and Recharge. Care of the Machine. Attachments. Insulator. Electrodes. Leyden Jars. Chains. Methods of Application. Indirect Spark. Direct Spark. Static Shock. Static Insulation. Static Breeze. Static Induced Current. Determination of Polarity.

For the medical use of **static electricity** any good influence machine, the type of which is represented by the Holtz machine, will suffice ; yet in order to obtain the best results from a machine, attention must be paid to its construction, to the size and number of its plates, to the method of driving it, and to its proper care.

In the best modern machines all the mechanical features of the Holtz machine have been practically preserved. The revolving and stationary plates have been increased in size and number, to augment the quantity of electricity generated. This increase, however, has its limit, and the prevalent opinion among the experienced is that, for practical purposes, the best effects may be obtained from a machine having eight plates,—four revolving and four stationary,—each of which has a diameter of from sixty to seventy centimeters. The stationary plates need not be circular, but may be made of two pieces, to allow of windows without necessitating any cutting in the body of the glass.

To protect it against dust and atmospheric changes, the machine should be incased ; and, for the same reason, the seams and joints of the case should be perfectly tight. A machine may be driven by hand or by means of a suitable motor (hot air, water, or electric). Hot-air engines for this purpose are expensive, troublesome, and noisy. Water motors may satisfactorily be employed, provided a sufficient water pressure be close at hand. The transmission of such force from a distance, by means of long belting, is unsatisfactory. When a proper electric source, such as a central lighting

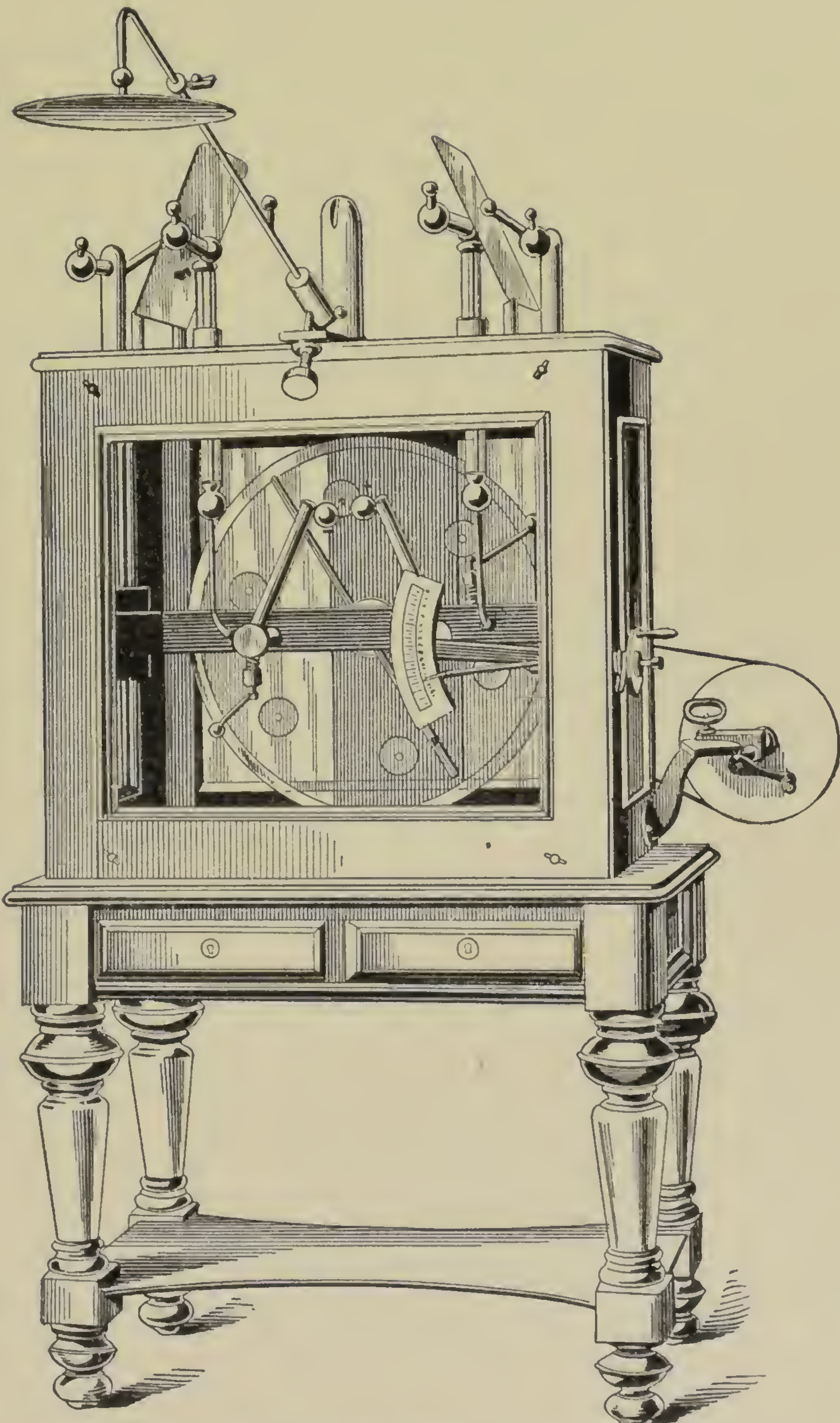

FIG. 89.—HOLTZ-TOEPPLER MACHINE.—(*Hirschmann, Berlin.*)

station, is available, preference should be given to an electromotor. The speed of such motors is best regulated by a properly constructed rheostat. Accumulators may be utilized for running the motor, provided that they can be charged from a central station.

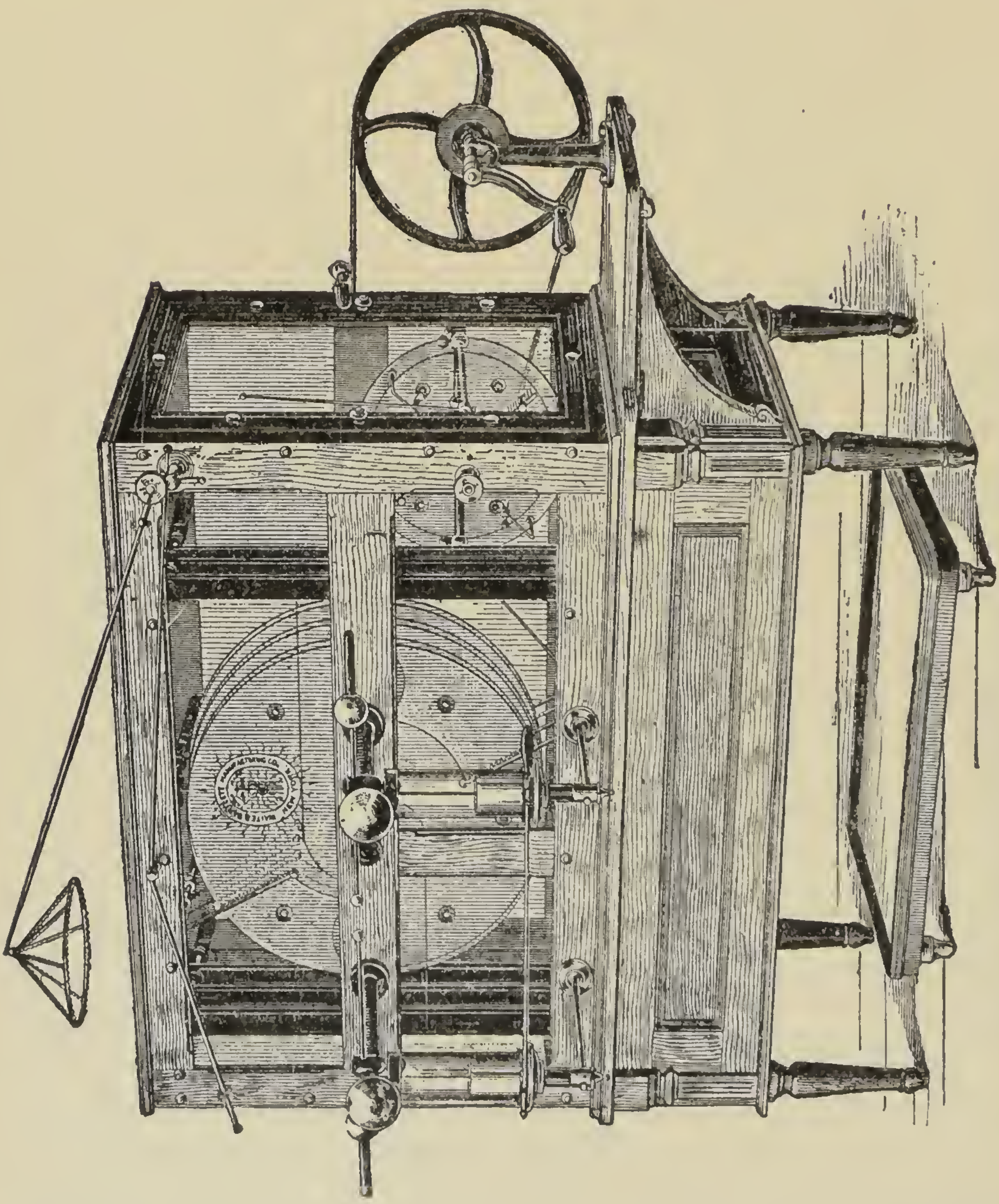

FIG. 90.—HOLTZ-TOEPPLER MACHINE.—(*Waite & Bartlett, New York.*)

Batteries for this purpose are too troublesome and too expensive. The machines made upon the Holtz-Toeppler principles that have seemed to me to be the most efficient are the foreign machines (one made by Hirschmann, of Berlin, is shown in figure 89), and the

one that I have made use of for several years, made by Waite & Bartlett, of New York, shown in figure 90. It is almost unnecessary to say that other manufacturers make machines in every way equal to those just mentioned, and I select these merely because I am most familiar with them.

A machine constructed upon entirely different principles and

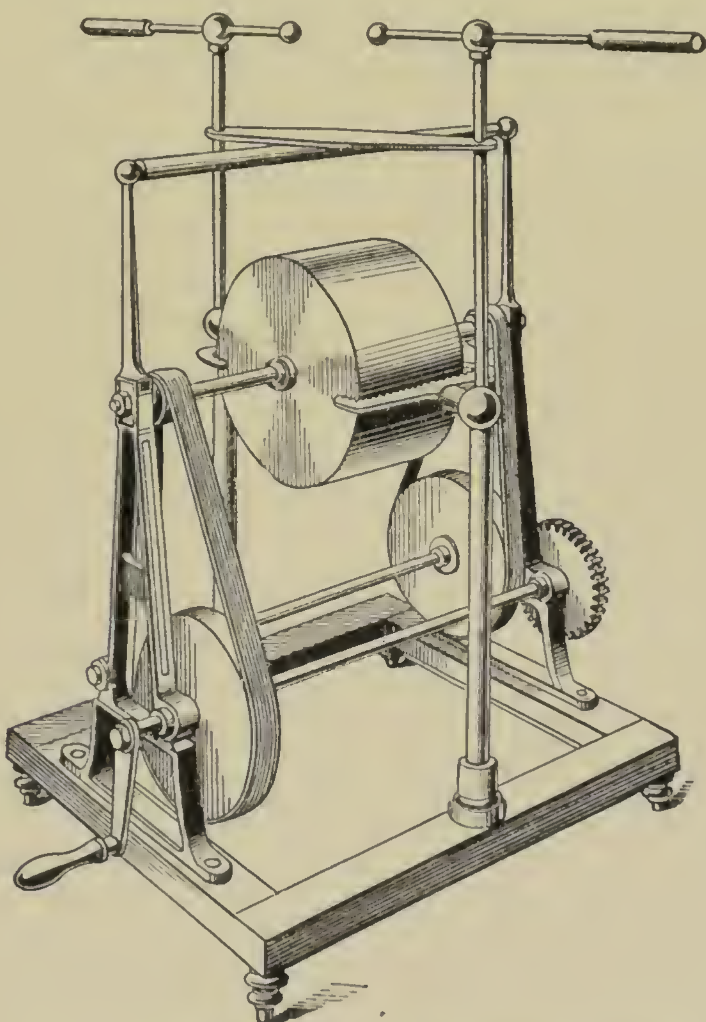

FIG. 91.—GLAESER'S CYLINDER MACHINE.—(*Vienna.*)

presenting certain advantages is made by Glaeser, of Vienna. This is a cylinder machine, and consists of two hollow drums of hard rubber, one somewhat smaller than the other. The smaller drum is air-tight, and is placed in the interior of the larger one. Both are made to revolve about a common axle, but in opposite directions. The machine is shown in figure 91 and requires no further explanation.

Its advantages consist in the durability and strength of material of the electric exciters, their form, and their air-tight construction. Hereby the machine may be made to functionate in all kinds of weather and under any atmospheric conditions. It gives larger quantities of electricity in comparison to the rotary force employed; like an electrophorus, it retains its charge for a long time; and it allows rotation in either direction without loss of charge.

The disadvantages are that the machine, not being self-charging, must be charged anew each time, and must, therefore, be made easily accessible, and not be inclosed in a glass case.

Loss of Charge and Recharging the Machine.

Loss of Charge.—The best machine may lose its charge, whether through having its plates turned in the wrong direction, through the entrance of moisture into the case and its deposition upon the plates, or through grounding both poles by leaving the chains hanging from them to the floor.

The plates may have become loosened from the axle and, in consequence, some may fail to revolve properly. The combs may have become displaced so as to touch the glass or to bear an improper relation to the paper collectors.

The majority of American machines of the Holtz type made for therapeutic purposes are now supplied with a small Wimshurst, for the purpose of exciting action in the Holtz when it loses its charge; and the latest machines of this kind have a small Wimshurst included in the case, and so arranged that its plates can be made to revolve at will, when the large machine is in action, and a charge be transferred to the plates of the latter. If the machine be not so supplied, it must be furnished with catskin rubbers, which bear upon the outer revolving plates, above the metal combs, and can mechanically be stretched over the face of the plate. To charge a machine by such catskin chargers both the machine and the chargers should be thoroughly dried. This may be done by exposure to the sun or by placing fresh calcium chlorid within the case, or by lighting a fire in the room, or, under exceptional circumstances, by all three methods combined. After the plates are thoroughly dry, one starts them by turning the driving wheel from left to right (facing the

machine). The chargers are applied lightly near the edge of the revolving plates for a second or two, and then swept across their faces every now and then until the machine starts. The poles should be approximated to within two centimeters, and no chains should be on the poles. If, notwithstanding this, the machine fails to work, a piece of catskin is warmed over a gas-jet, the machine is set in motion, and the warm catskin applied as a rubber to the outer plate as close as possible above the metal combs.

Care of the Machine.—To be able to obtain the best effects from any machine, it should receive a certain amount of care. It should be kept in a well-lighted, dry room. The accumulation of moisture and dust upon the poles or electrodes is one of the most serious obstacles to the successful working of a machine; hence all its metallic parts should be rubbed each morning with silk or chamois skin. All bearings and the axle should be kept well oiled, and the belt of the machine should be tightened occasionally.

It is well also to have fresh calcium chlorid in the case constantly, so as to keep the air of the interior dry. In winter this is not always necessary, but in summer it is absolutely essential. The calcium chlorid is best distributed among several dishes, each of which may hold 500 grams or more. So soon as water accumulates on the calcium it should be poured off, or the salt may be rebaked in a slow oven, the heat of which must not be great enough to boil it.

Attachments for the Machine.—The attachments for the machine consist of:

1. An insulated platform or some other means of insulating the patient. Insulated platforms are cumbrous, and take up considerable room. If employed, it will be found convenient to have them so arranged that they can be pushed under the machine when not in use. Much handier is a rubber or glass plate upon which any chair may be placed.

2. A set of electrodes, consisting of a large and a small brass ball, a metal point, a wooden point, a metal roller, an umbrella electrode, a pistol electrode, sponge-covered electrodes, and a ring to hold the chain away from the patient. These electrodes and chain-holder, as furnished by Waite & Bartlett, are shown in figure 92.

3. A set of brass chains of varying lengths; hooks for the

attachment of the chains; Leyden jars of different sizes, and a brass rod for connecting the outer coverings of the Leyden jars when they are in use.

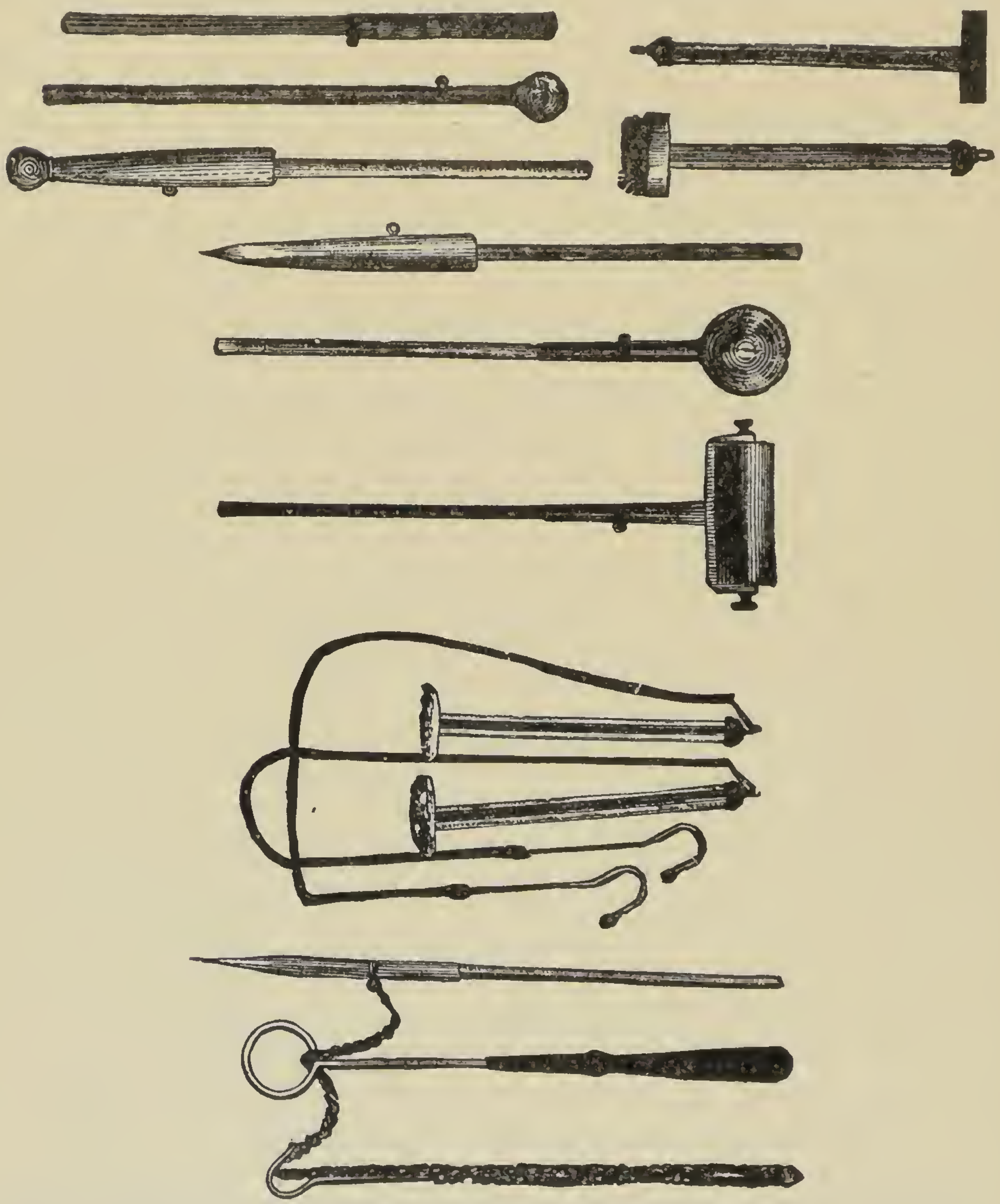

FIG. 92.—ELECTRODES AND ACCESSORIES FOR STATIC MACHINE.—(*Waite & Bartlett, New York.*)

Methods of Application of Static Electricity.

The methods of applying the static current are the following:

1. By the indirect spark.

2. By the direct spark.
3. By the Leyden jar spark or static shock.
4. By static insulation.
5. By the static breeze.
6. By the static induced current.

The **indirect spark** is applied by placing the patient first upon the insulated platform (Fig. 93); he is then connected with the machine by means of a chain which is hooked over one of the poles, either positive or negative; the other end being attached to the chair upon which the patient sits. A chain is then attached to the other pole of the machine and is grounded. Grounding is best done by attaching the free end of the chain to a gas fixture or water-pipe; when this is not possible, it may be dropped upon the bare floor.

The poles of the machine are now widely separated, and the wheels put into rapid motion. It will be noticed at once that the hair of the subject rises up, and if the room be dark, a purplish light will be observed to escape from his body. This condition is called **static insulation**, and the patient may thus be charged from the positive or negative pole, according to the connection. Finally, the part of the body to be specially acted upon is approached by a brass ball electrode. This electrode is attached to a gas- or water-pipe by means of a brass chain. The brass chain must be passed through a ring attached to an insulating handle, so that it may be kept away from the patient's body. When the ball comes to within a certain distance from the patient, a discharge of accumulated electricity occurs in the form of a spark; this is known as the indirect spark, because the electricity takes an indirect course (through the earth) to form a circuit.

The length of the spark is directly proportional to the generating power of the machine. The volume of the spark is modified by the size of the brass ball and of the electrode. A large ball will produce a heavier spark than will a small one. By using a wooden ball instead of a brass one numerous very fine sparks are simultaneously obtained.

The removal of the clothing is unnecessary. The patient may stand upon the platform if this be preferable to sitting.

The Direct Spark.—Here the patient is attached in the same

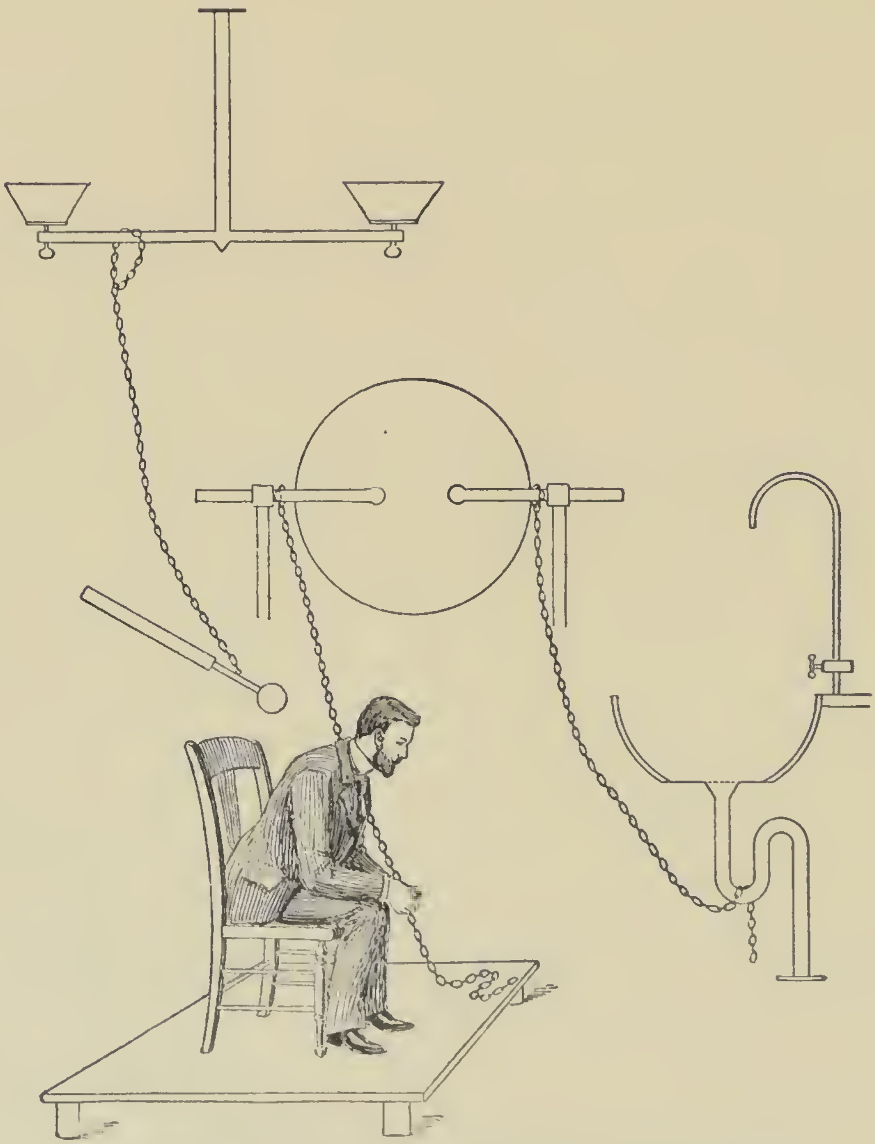

FIG. 93.—METHOD OF APPLYING THE INDIRECT SPARK.

manner to one pole of the machine, while the electrode is directly attached to the other pole by means of a chain. The ring and the ball electrode are employed, as in the former method. The length of the spark to be administered is regulated by the extent of separation of the poles of the machine and the speed of revolution of the plates. The further apart the poles, and the more rapid the

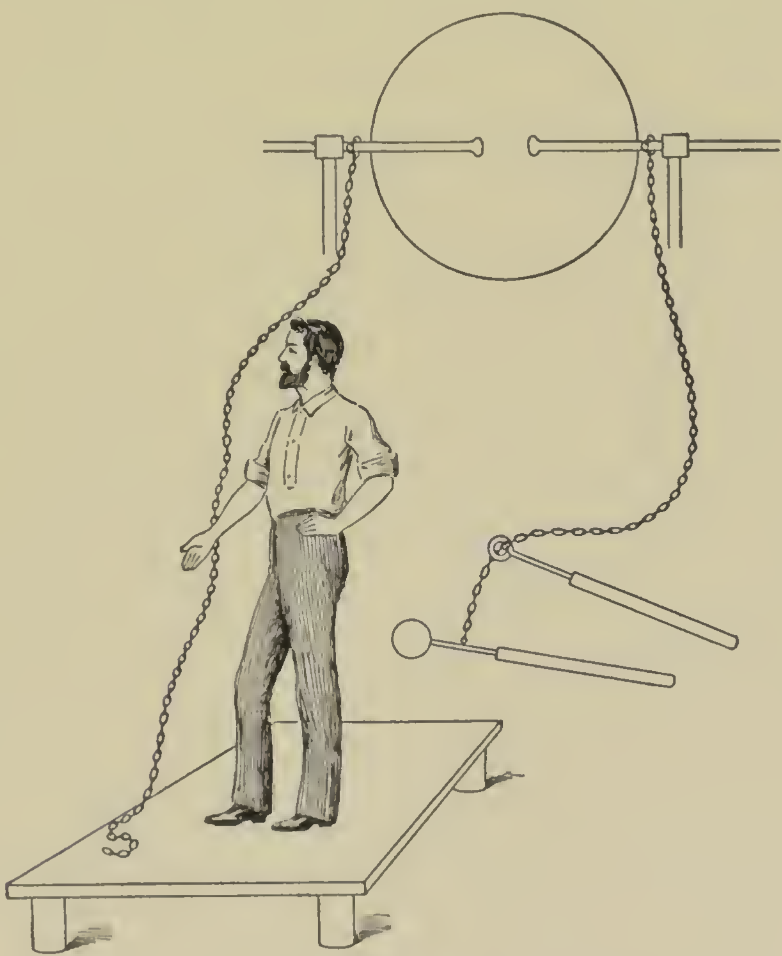

FIG. 94.—METHOD OF APPLYING THE DIRECT SPARK.

revolution of the plates, the longer and the more severe is the spark. (See Fig. 94.)

Leyden Jar Spark (Fig. 95).—In this method a pair of Leyden jars are first attached to the poles; their outer coverings of tin-foil are then connected by means of a brass rod. The poles are then brought into close approximation, and the electrode and the chain leading to the patient are arranged as in the preceding method.

The strength of the shock is proportional to the separation of the poles and the size of the jars. It is, therefore, advisable in using this method to approximate the poles as closely as possible, without actual contact, and to use the smallest of jars. An increase of strength can be obtained by separating the poles and putting on larger jars. In this method the application is best made to the bare skin. Its action is very severe, and it should be used with extreme caution.

Localization.—In the preceding forms of application it is some-

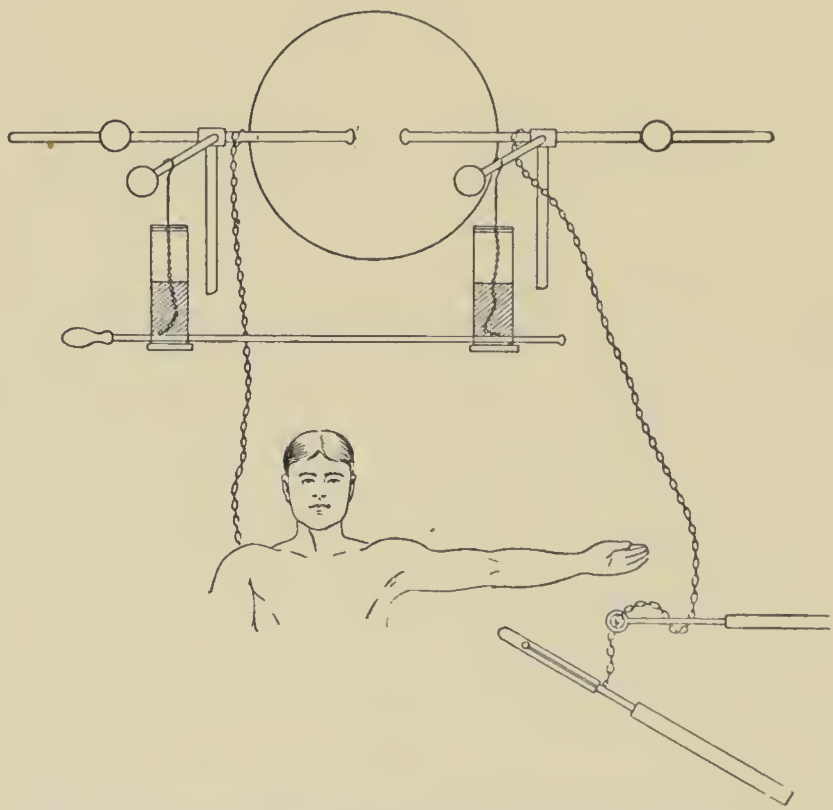

FIG. 95.—METHOD OF APPLYING THE LEYDEN JAR SPARK.

times difficult to localize the spark to special parts of the body by means of the ordinary ball electrode, for the reason that the current causing the spark always seeks the line of least resistance. In order to localize the spark more precisely a directing electrode, as Morton's spark electrode (Fig. 96), will be found of service.

A friction spark or **static massage** may also be conveniently applied, according to any of the methods just described, by means of the roller electrode shown in figure 97. Such an

electrode, however, is not essential, as a large ball electrode will answer the same purpose.

Static insulation has already been described in speaking of the indirect spark (Fig. 93). The patient simply is charged from either pole for a variable length of time. One pole is attached to the insulated platform upon which the patient stands or sits; the other pole is grounded by a chain running to the floor or to gas- or water-pipes. The poles of the machine are separated as widely as possible before the wheels are set in action.

FIG. 96.—MORTON'S SPARK ELECTRODE.

The Static Breeze.—This method consists in the withdrawal of the static charge from a patient, by means of an electrode that is made up of one or more points. The breeze may be applied directly or indirectly. If indirectly, the breeze electrode is grounded, as described in the method of the indirect spark; if directly, one pole of the machine is connected with the insulated platform, the other with the electrode.

When it is desirable to apply this breeze to the head, a metal cap studded with points is hung over the head of the patient and is

FIG. 97.—ROLLER ELECTRODE.

grounded. It should not touch the patient's head or hair. Such an electrode is shown attached to the machine in figure 90 (p. 122). When it is desired to concentrate the breeze upon any special part of the body and to make an application of some duration, the concentrator and stand shown in figure 98 will be found serviceable. When used, one pole of the static machine must be connected by means of a chain to the metal at *D*, the other pole, by means of a chain also, to the platform or patient. The point of the

concentrator must be brought near enough to the patient for the current to bear on the part to be treated.

The **static induced current**, so called, and elaborated by W. J. Morton, of New York, in nature resembles somewhat the current derived from the fine wire coil of a medical induction coil, as it is an alternating and interrupted current, but its potential is

FIG. 98.—CONCENTRATOR AND STAND.

very much greater than that of any medical induction coil ; it is in reality an oscillating current of high frequency, as has already been shown.

To produce this modification of current we first hang a pair of Leyden jars upon the arms of the machine. Chains, or better still, insulated wires, should then be attached to the outer coverings of

the jars (see Fig. 99), and to the other end of each of these wires is attached an electrode for use upon the body of the patient. These

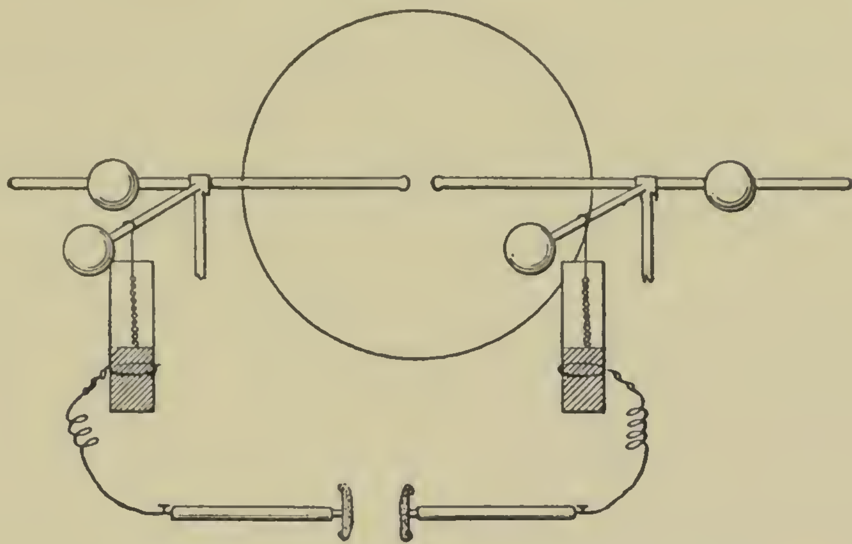

FIG. 99.—METHOD OF PRODUCING THE STATIC INDUCED CURRENT.

electrodes are best covered with sponge and should have long insulated handles.

The poles of the machine should be brought into contact before the plates are made to revolve. This is very important, because

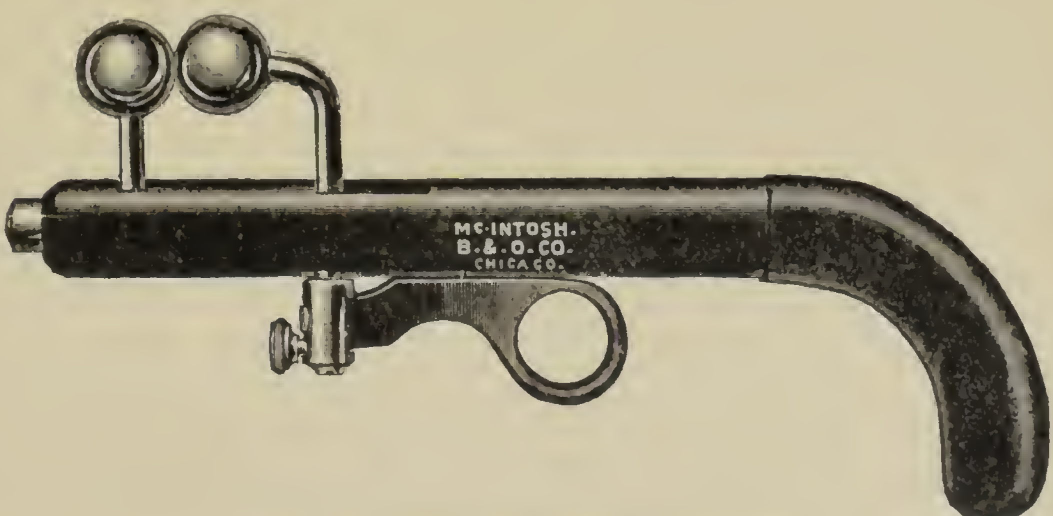

FIG. 100.—MORTON'S PISTOL ELECTRODE.

the current becomes much intensified by a separation of the poles. No insulation of the patient is necessary in this method. The strength of the current is determined by the size of the Leyden

jars and by the extent of separation of the poles. It can, therefore, be varied at will.

Morton, by means of a special electrode, avoids the inconvenience entailed by constantly separating and approximating the poles of the machine. The spark is thus not abolished entirely, but is arranged to occur at a distance from the patient, and, of course, forms part of the circuit in which he is included. This electrode is shown in figure 100; the spark occurs between the two balls, which may be separated or approximated by means of a trigger. The applications of this handle are manifest, and when connected with a suitable electrode, the spark may be applied, if so desired, to any accessible body-cavity.

Characteristics of the Franklinic Current.

The **electricity yielded by static machines** is of very high electromotive force. The number of volts can be estimated approximately according to the length of the spark. The following table shows the figures of Mascart for recognition of the **voltage of current** according to the length of the spark:

VOLTAGE OF FRANKLINIC CURRENT.

Length of Spark.	*Tension in Volts.*	*Length of Spark.*	*Tension in Volts.*
0.1 cm.	5,490	6.0 cm.	101,400
0.5 "	26,730	7.0 "	107,700
1.0 "	48,600	8.0 "	112,500
1.5 "	57,000	9.0 "	115,800
2.0 "	64,800	10.0 "	119,100
3.0 "	76,800	12.0 "	124,200
4.0 "	77,300	15.0 "	127,800
5.0 "	94,800		

The **ampèrage** of the current, however, is exceedingly small, and the chemical effect, for all practical purposes, is *nil*.

Polarity.

It is sometimes desirable, when using a static machine, to know which prime conductor is at a positive, and which at a negative, potential. The poles of the machine may be best differentiated by observing a machine while in action in the dark, with the external poles connected. The positive side can then be

recognized by the fact that the tips of the collecting comb show points of light, while upon the negative side the light appears in a brush-like form.

In the light, the poles may be differentiated by the form and color of the spark that passes between the external conductors of the machine. If, thus, the balls of the conductors be separated to within two centimeters of each other, the spark stream that passes between them shows a distinct violet portion, which begins at the ball by a bright point; this violet part of the stream indicates the negative pole, while the positive pole is characterized by a bright area of white light lying near it. If a burning candle be placed between the poles of a machine in action, the flame will be diverted toward the positive pole.

Since machines that have not been in use for some time do not always charge themselves in the same direction, it is necessary to determine the polarity by one of the foregoing methods.

CHAPTER II

GALVANIC APPARATUS AND ITS USE

Source. Batteries. Dynamos. Regulators. Selectors. Rheostats. Volt Controllers. Arrangement of Resistance in Circuit. Reversers. Interrupters. Combiners. Measurement. Milliampèremeters. Voltmeters. Electrodes. Cords.

Galvanic Apparatus.

For the application of galvanic or dynamic electricity in its various modifications for medical purposes we require, first, a proper **source of electricity**—batteries or dynamos; secondly, some arrangement by which the electromotive force and ampèrage of the current can be **regulated or modified**; and in addition to these a means for **reversing** the poles, a means for **measuring** both the electromotive force and the current strength, and a means for **leading the current** to the body of the patient.

As many of these appurtenances are essential for the application of all forms of current, no matter what their source,—constant, magneto- or volta induced, sinusoidal, and high frequency,—it will be more convenient, in order to avoid repetition, to begin by describing the accessory apparatus, and then to give a description of the medical apparatus itself, as employed for the generation or application of the different currents.

Means by which the Current may be Regulated.

Cell Selectors.—Rheostats.—Volt Controllers.—The most important factor in the use of dynamic electricity, regardless of the source from which it is derived or of the manner in which the character of its electromotive force may be modified for special purposes, is its **control**.

We know that the strength of a current—its ampèrage—may be increased or decreased by an increase or decrease of electromotive force, or by decreasing or increasing the resistance

through which the current flows. This increase or decrease of the current practically means its control.

As the resistance of the external circuit (human body) is in all electrodiagnostic and electrotherapeutic applications very large, it is necessary, when cells constitute the source of current supply, so to arrange these cells that the pressure of the current may easily overcome the large external resistance. In order to obtain such a pressure, a large number of cells connected in series must be employed. According to Ohm's law, the pressure of a current, when we are dealing with a large external resistance, is almost directly proportional to the number of cells employed. It is, therefore, necessary that every battery that is to be used for electromedical purposes should have some arrangement by which the pressure (E M F) and the current strength may be regulated. This may be accomplished by the use of a *cell selector*.

Cell selectors possess the advantage of regulating the pressure, and with this also the current strength, but they present such serious disadvantages that they have been to a great extent displaced by other apparatus. Yet so many portable batteries made by various manufacturers are supplied with this means of current regulation alone that a description of their essential features becomes necessary.

A good selector must possess certain prime qualities: (1) It must admit of an *increase* or a *decrease* of *electromotive force*, through the introduction of *one cell* at a time; (2) it must permit of such increase or decrease *without producing any interruption* in the flow of the current.

All selectors are constructed upon one of three principles: the *crank*, the *rider*, or the *plug* system.

The best **crank selector** is the one described by R. Remak. It consists of a plate of hard rubber, upon which are arranged, in a circle or semicircle, the metallic buttons through which the connection is made. A metal crank pivoting at the center of the circle can be brought into contact with each of the buttons successively, thus allowing the current from a greater or smaller number of cells to flow accordingly through the button upon which it rests. The contact buttons, which are insulated from one another, must still

be so close to one another that the crank touches a button while it is covering the next following one. By an arrangement in the form of two semicircles—the first of which selects one cell at a time, from 1 to 10, and the second selects five cells at a time, from 5 to 50—any desired number of cells from 1 to 60 may be introduced singly; yet only twenty contact buttons are used.

The **plug selector**, or Brenner's selector, is so constructed that, instead of buttons and a crank being made use of, brass plates and plugs are employed. Each metallic plate has a semicircular piece cut out of each end, so that when the ends of two different plates are approximated, but not in contact, a circle is formed into which the metallic plug fits tightly. When a plug is introduced at a certain hole, all the cells up to the number indicated by that hole are thrown into the circuit. The withdrawal of the plug at once breaks the current, and thus a sudden break and make of the current from any desired number of cells may be effected. This supposed advantage is much better attained by other means (commutator).

In order to avoid such breaks of the current in the ordinary use of this selector it is necessary to employ two plugs, one of which, for example, is put into hole 1 and the second into hole 2; then plug 1 is withdrawn and placed in hole 3; thus, by taking one plug out and putting it into the hole immediately beyond the other plug, the entire battery may be introduced cell by cell.

This cell selector is so made by some manufacturers that, instead of metal plates with holes for the plugs to fit into, metal plugs over which a split metal sheath fits tightly are employed. Two such sheaths are attached to a bifurcated conducting cord, and they are placed over the plugs in the same manner as described for placing the plugs in the holes.

The disadvantages of both of these forms of selectors are so great that it is to be hoped they will soon cease to be a part of instruments of American manufacture, as they have long since ceased to be found on European apparatus.

The **rider form** of selector may fairly be represented by that of Stoehrer. It consists of a rectangular strip placed horizontally upon a base; along both edges of the former are fastened, at regu-

lar intervals, plates of brass that are connected with the cells of the battery. A metallic rider is placed over the median portion, and is movable between the two rows of plates, and forms a metallic contact between them. If the rider is placed at 0, no current passes; if at the point 2, two cells are brought into action; thus the further the rider is removed from 0, the more cells are introduced. (See Fig. 101.)

For many years a number of physicians have made use of a selector that Dr. Rudisch and I described in 1884, and that has given great satisfaction to all who have employed it. This selector is one that, although a combination of all three systems, is best understood by describing it as of the rider variety. It consists of a strip of hard rubber that is perforated by as many metal plugs as

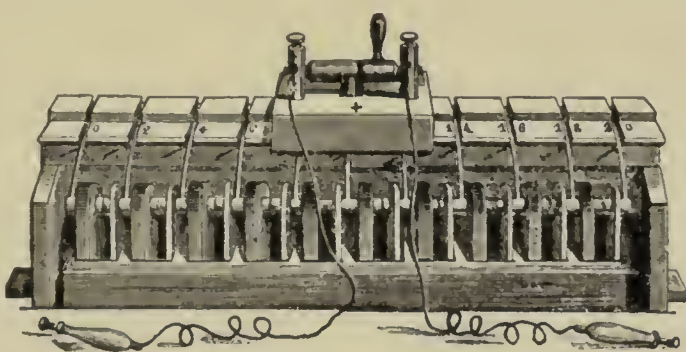

FIG. 101.—RIDER CELL SELECTOR.

there are cells in the battery; each plug ends in a metal head, and is connected below to its corresponding cell. Two strips of metal run along the sides of the rubber strip from end to end (Fig. 102, *m 1*, *m 2*). The entire base is surmounted by two riders that are freely movable in either direction, *R 1*, *R 2*. These riders consist of a hard-rubber body that serves as a handle, to the bottom of which is attached, by means of a strong spring, a metallic plate half as large as the head of a plug (Fig. 103, *p*, *p*). The whole rider is kept in place by two side-pieces, best described as clamps (Fig. 103, *c*, *c*, *c*, *c*), and that are in close connection with the metallic strips *m 1* and *m 2*, figure 102; it is lined by a thin plate of metal, so that a direct metallic connection is formed between the rider and the metallic strips. This metal lining is not continuous, but is broken

at the upper clamp of the one rider, and the lower clamp of the other (Fig. 103, *Br 1*, *Br 2*). The selector is connected and operated as follows:

The metallic strips are connected one with each binding post or electrode. The zinc of each cell is connected seriatim with the corresponding plug of the selector. It will thus be seen that, the cells being connected among themselves in series, all the cells that lie between the plugs upon which the riders rest will be in the circuit, while those lying exteriorly to the riders are not in circuit. For example, let the rider *R 1* be placed upon button 2 and the

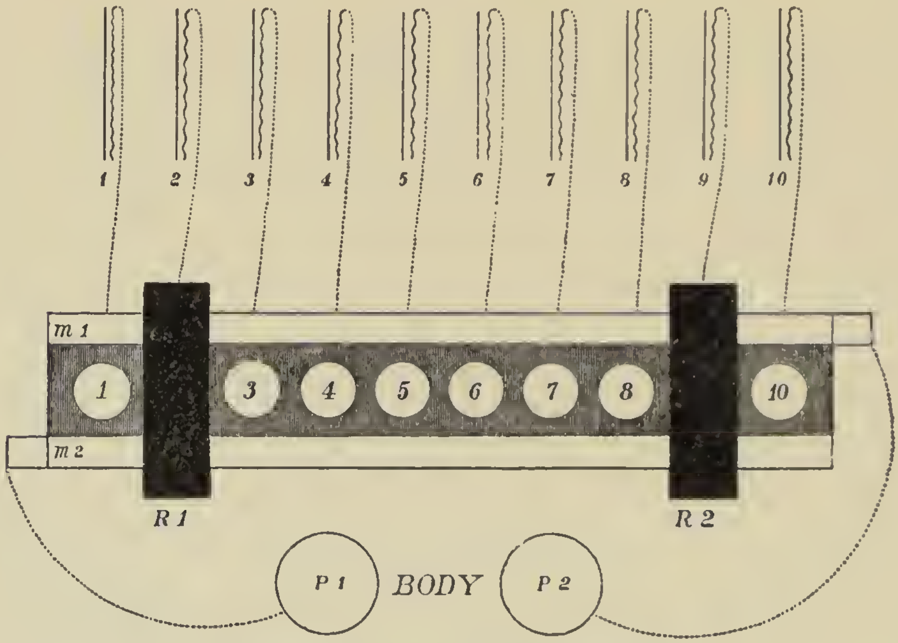

FIG. 102.—COMBINED CELL SELECTOR.

rider *R 2* upon button 9. The current will pass from the second cell to the second plug, then into the first rider, *R 1*, placed upon this plug; then, because the connection above is broken, it passes to the lower metallic strip, and thence through the connecting wire to the binding post (*P 1*, Fig. 102). Thence the current passes through the body connecting the two posts, to the second binding post, *P 2*, through the wire to the upper metallic strip, along this to rider *R 2*, and thence into plug 9, upon which the latter rests, thus completing the circuit. The advantages of this selector, which may be variously modified, are that: (1) There is always

a firm connection between the rider and the plugs. (2) The cells can be introduced into the current singly. (3) The first cells of the battery do not become worn before the others. Whatever may be the position of the riders, the only cells comprised in the circuit are those situated between the riders, and all cells situated in front of the one and behind the

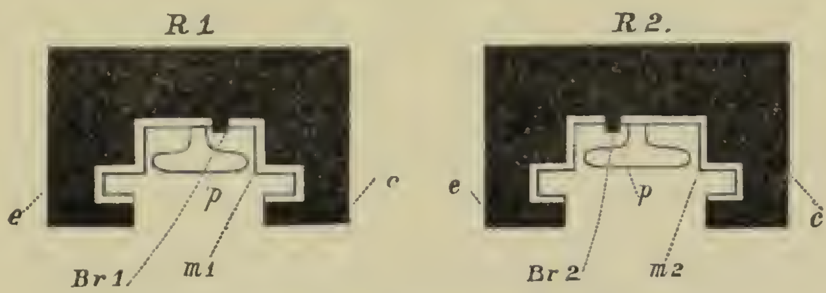

FIG. 103.—RIDERS OF COMBINED CELL SELECTOR.

other rider form an isolated series. (4) By means of this selector any disorder of function in the circuit of any cell may be surely and quickly located; thus, if the riders are approximated so that each one covers the plug connected with the adjoining cells, and they are then moved together along the selector base, each cell is taken singly, and any disorder will at once be indicated by a galvanometer placed in the circuit.

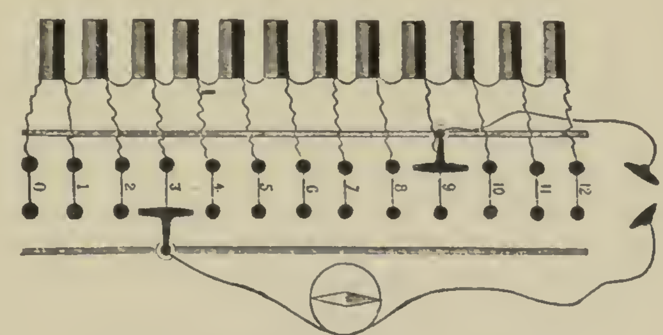

FIG. 104.—GAIFFE'S CELL SELECTOR.

A similar contrivance, shown in figure 104, has for many years been made use of by Gaiffe, of Paris. A circular form may also be given to this selector.

Regulation by Rheostat.—Instead of increasing or diminishing the current strength by increasing or decreasing the voltage, as is

done when a selector is employed, the current strength may be regulated more practicably through the introduction of a variable resistance, a **rheostat**, into the circuit. We then make use of the entire electromotive force of the source at our command, or of a suitable part of it, and reduce the ampèrage by increasing the resistance in the circuit.

The method of making use of the entire available current and regulating its strength by means of a rheostat has one very grave practical objection, and that is that the intensity (pressure) of the entire source accompanies even the smallest amount of current strength applied, and thus materially increases the pain of the application. This objection, however, can readily be obviated, for there can no longer be any doubt that the increase of pain with an increase of the current is dependent upon the manner in which the resistance is placed in the circuit. There certainly is a difference between applying, say, ten milliampères of current at a pressure of seventy-five volts, through a resistance placed in series with the patient, and applying the same number of milliampères with the resistance so placed that the pressure is reduced to a degree just sufficient to overcome the resistance of that part of the body which is being treated. The accompanying sketch illustrates the manner in which this regulating resistance should be employed. (See Fig. 105.)

The regulation is here effected by means of the shunt principle, explained on page 65, and which, practically applied, is shown in figure 105. B is a battery from which the current flows from + to R (resistance); a certain portion of this current is forced through this resistance and passes to —, thus completing the circuit.

This portion of current is wasted, and therefore it is well to make the resistance as large as is practicable in proportion to the pressure in the main, thereby minimizing the loss of current. If, for instance, our battery represents an electromotive force of 40 volts, and we introduce into the main circuit a resistance of 10,000 ohms, the current forced through this resistance will be $C = \frac{E.M.F.}{R} = \frac{40}{10,000}$, or 0.004 ampère, which amount represents the actual loss of current. By a shunt we now derive our therapeutic current: one

conductor is attached at a point C, and the other to a bar, which carries a slide contact C^2, electrically connected to this bar.

As the flow of current through a shunt is directly proportional to the resistance in the main, no current will be obtained at T+ and T— when the slide contact C^2 is nearest to C,— that is, if there be no resistance to speak of between C^2 and C; as soon, however, as we slide C^2 away from C, and thus introduce resistance, a current will be obtained at T+, T—, whose intensity will increase until all the resistance has been interpolated between C and C^2.

The comparatively feeble currents employed in therapeutics

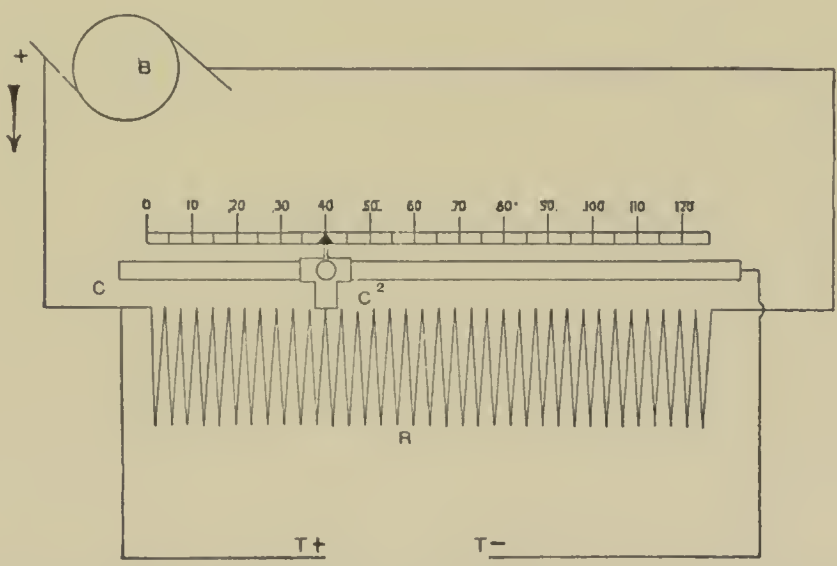

FIG. 105.—SHOWING REGULATION OF CURRENT BY RESISTANCE IN SHUNT.

admit of the use of wire, carbon, or water as such resistance material.

Wire rheostats are frequently used, and are the only suitable ones for measuring purposes, as they are the most accurate and least subject to change. The principle of their construction has already been described (see Measurement of Resistance), and the metal rheostats employed in medicine are all more or less modified resistance coils or boxes.

Whenever, as is the case in all therapeutic work and in nearly all diagnostic work, direct measurement of the interposed resistance is

not required, a single wire coil may be employed. The resistance of this coil must then be so great that when the entire coil is in circuit practically no current can pass. Such a single wire coil may also be replaced by a column of some other material that is of much higher resistance than metal wire and is much less expensive. Such materials are graphite and liquids.

Graphite Rheostats.—Convenient and inexpensive rheostats furnishing a high resistance and admitting of gradual and extensive variations of the current may be made of graphite. The simplest practical form of such rheostat is that shown in figure 106, which was constructed by Dr. J. Rudisch, of New York, and which I demonstrated to the American Neurological Association in 1881. This instrument consists of a plate of ground glass, G (Fig. 106),

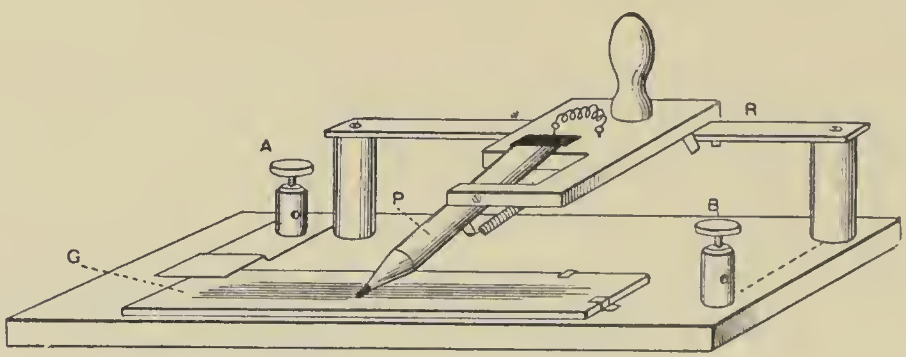

FIG. 106.—GRAPHITE PENCIL RHEOSTAT.

upon which glides a thick graphite pencil, P; as the pencil is moved to and fro over the glass, graphite is rubbed into the glass and a path furnished for the current to flow. The current enters the instrument at the binding post A, flows from there to the graphite mark on the glass, along this mark to the pencil, up through the pencil along the metallic connection R to the binding post B. It will be apparent that the less graphite there is upon the glass, the greater will be the resistance; that, therefore, the resistance may be varied at will by rubbing more graphite on the glass, and by increasing or decreasing the distance between the point of entrance of the current and the graphite pencil.

This rheostat has been modified by giving it a circular form and by using a metal spring instead of a pencil for contact with the

graphite, which then must be supplied from some other source (Fig. 107).

Pulverized carbonaceous material is sometimes substituted for graphite, alone or in combination with some fixing substance, and pressed into a groove in an insulating plate. Such a rheostat is

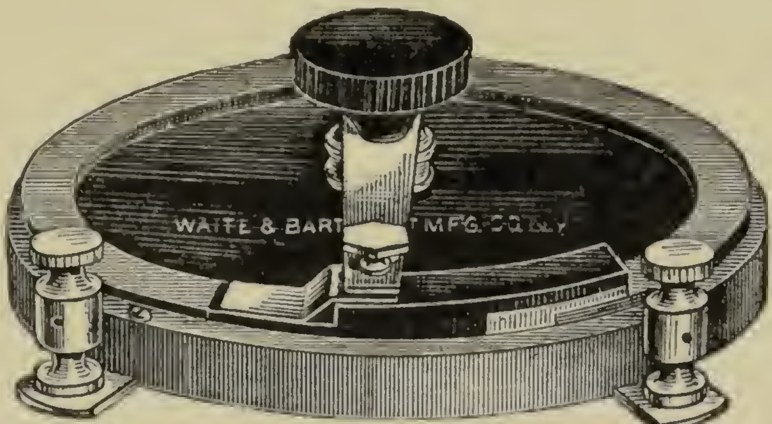

FIG. 107.—MODIFIED GRAPHITE RHEOSTAT.

shown in figure 108. Here a revolving handle makes direct contact with a carbon column in the groove beneath. The length of the carbon column inserted between the terminals can be varied by turning the handle. The resistance is proportional to the length of the carbon column included between the handle and the starting-point.

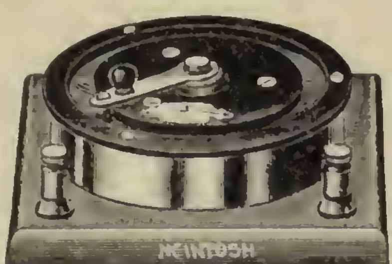

FIG. 108.—MODIFIED GRAPHITE RHEOSTAT.

Another form of carbon rheostat, one that I have used for years and found very satisfactory when employed with the battery current, is the **Vetter rheostat.** The fundamental principle upon which the action of this instrument depends is the effect of variation in resistance that takes place in a quantity of carbon subjected to a change in pressure. Figure 109 shows the instrument complete,

and figure 110 illustrates its working parts. In this instrument a quantity of finely powdered carbon is contained in a small rubber

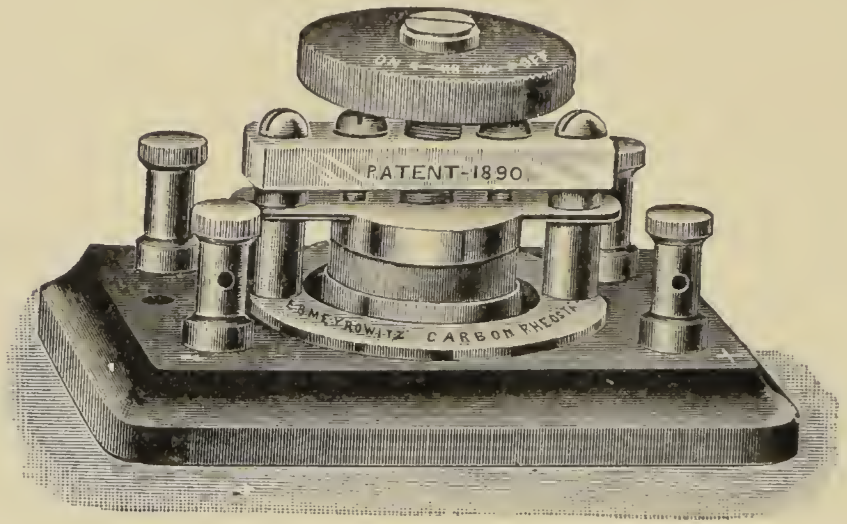

FIG. 109.—VETTER RHEOSTAT.

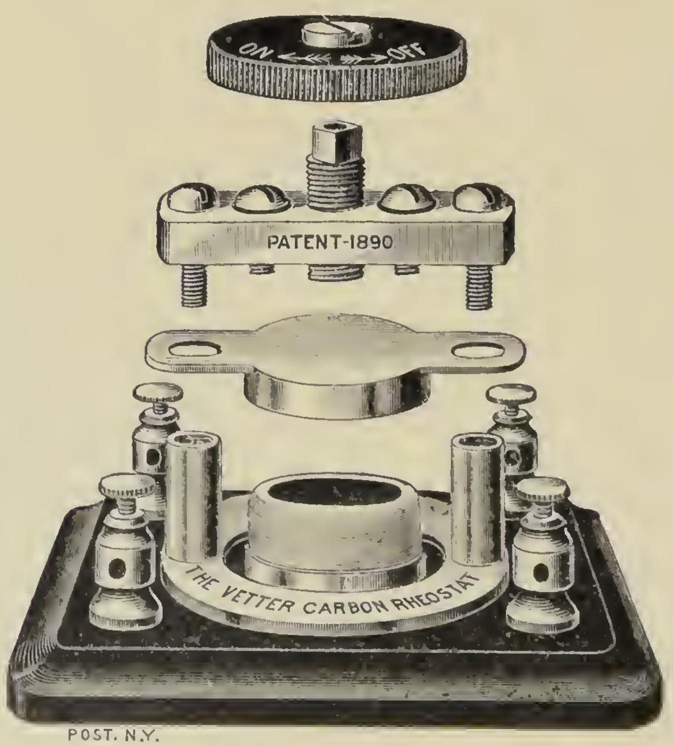

FIG. 110.—WORKING PARTS OF VETTER RHEOSTAT.

cylinder placed between two metal plates, the opposing ends of a circuit. The lower plate is affixed to the base of the instrument, and

the other, traveling on upright guides, can be depressed, by means of a screw, so as to compress the carbon in the rubber cylinder. In its ordinary position—that is, when the rubber cylinder is not compressed—the contained carbon is held by the rubber tightly against the poles, and in this elongated position offers the greatest degree of resistance to the current.

As the knob B is turned "on" it forces the upper pole down against the carbon, which, for lack of space, bulges the rubber cylinder out at the sides, thus diminishing the quantity of carbon

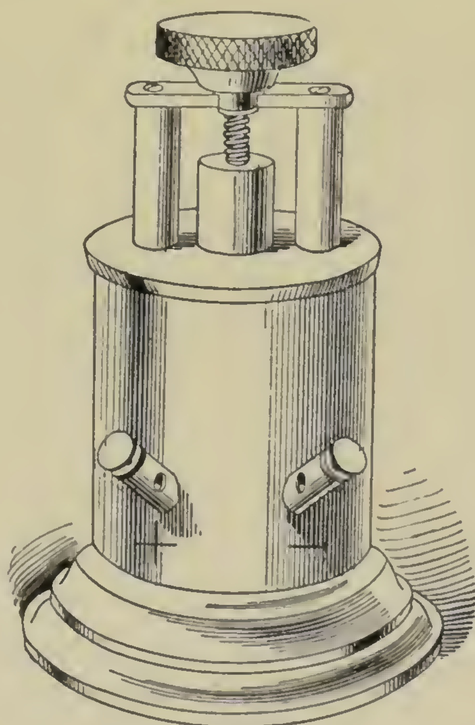

FIG. 111.—FLUID RHEOSTAT.

and the distance between the poles until, if required, "hard contact" is made. The reverse order of events takes place when the knob is turned "off," the flexible quality of the rubber causing it gradually to resume its former shape, and, by forcing the carbon back, to keep it in good contact with the poles. The mechanical construction, which involves the principle of the letterpress, is almost perfect, and, electrically considered, it offers great advantages.

Fluid Rheostat.—Another form of rheostat much used in medicine is the *fluid rheostat*. The principle of such an instru-

ment is that a column of water shall be so contained in a vessel that, by means of a pair of separate metal electrodes, a greater or smaller part of the column of water may be interposed between the terminals; then the further apart the terminals of these electrodes may be, the greater will be the column of water between them, and the greater the resistance opposed to the flow of current. The scope of such an instrument will depend upon the length of the column of fluid, the diameter of the electrodes, and the conductivity of the fluid. An excellent instrument of this kind is made by Hirschmann, of Berlin, and is shown in figure 111.

The chief objection to the use of such instruments, however, is that the polarization that necessarily takes place in them produces

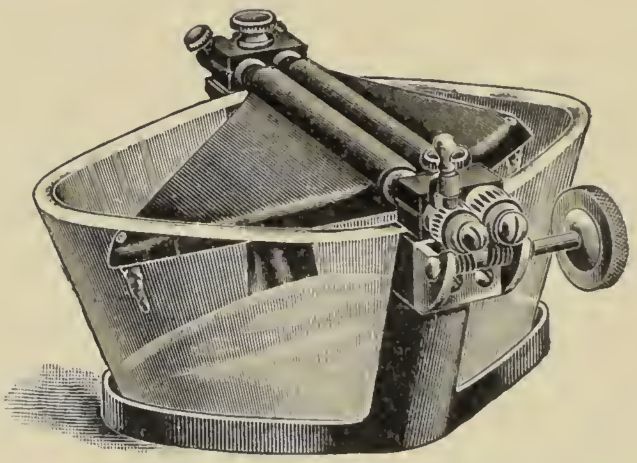

FIG. 112.—IMPROVED FLUID RHEOSTAT.

a constant change in their resistivity. The use of a depolarizing fluid is impracticable; as any fluid of sufficient depolarizing power would be so good a conductor of electricity that the rheostat containing such would be unserviceable.

In the form shown in figure 112 these difficulties are practically overcome. The electrodes and connections exposed to the fluid are made of carbon and tin and will not oxidize, and the water can easily be changed from time to time. I consider this the best form of water rheostat.

The Choice and Use of Selectors and Rheostats.

If **selectors** are to be used at all, they should, in my opinion, be employed only for the regulation of the **voltage** of a battery

current, or for purely scientific purposes. In the former case the number of volts that we desire to work with should be selected by means of the cell selector, and the current given by this voltage regulated by means of a rheostat. It is, therefore, better to have a small selector,—one that selects the cells in series of five or even ten,—and then to regulate the strength of this current by means of a rheostat. By this means all the advantages of volt controlling may be obtained, while the disadvantages caused by complicated wiring, and therefore by more frequent disorder, are obviated.

For purely scientific purposes a selector that selects the cells singly and seriatim is desirable. Of the choice of the rheostat, it may be said that metal rheostats are more accurate. They are the best for scientific purposes and measurement, and when expense is no objection, they should always be employed.

In view of the fact that the selector is of use only with battery currents, it is desirable to have some other device for the reduction of pressure, together with a satisfactory rheostat. This combination of volt controller and rheostat is undoubtedly the most scientific, and practically the most satisfactory, method of regulating a current for diagnostic or therapeutic purposes.

The **mode of regulation** of the current by means of a change of voltage or of pressure is apparent when we recall that if in a circuit the resistance remain constant, the current will vary directly with electromotive force. For instance, if the resistance of a wire be two ohms and the electromotive force at its terminal two volts, one ampère of current will flow. If the voltage be doubled (four volts), the current also will be doubled. Now, if the current passing through the conductor remain constant, we see from the formula $E\,M\,F = C \times R$ that the electromotive force between any two points in the conductor will be directly proportional to the resistance of the conductor between these two points.

Let us return to our assumed battery of forty volts pressure, with a resistance of 10,000 ohms in the main circuit, and let us assume, furthermore, that the resistance is made up of the cylindric body, the total or highest resistance of which lies between its terminals E and o (Fig. 113), and that this resistance is evenly distributed along the surface of the cylinder.

Then a voltmeter whose terminals are brought into contact with the surface of said cylinder will indicate an intensity of current that is in direct proportion to the length of the part of the cylinder that lies between these terminals. Thus, if one-fourth of the entire cylinder be connected between the terminals of the voltmeter, the meter will indicate one-fourth of the initial voltage. If, now, a scale be affixed to the resistance coil,—a scale that has been properly graded so that each division corresponds to one volt,—then the voltage may be read directly from this scale without the use of the voltmeter. But inasmuch as we are also introducing resistance directly into the circuit, not only the voltage, but also the current itself, will thereby be reduced. Herein we have, therefore, a reli-

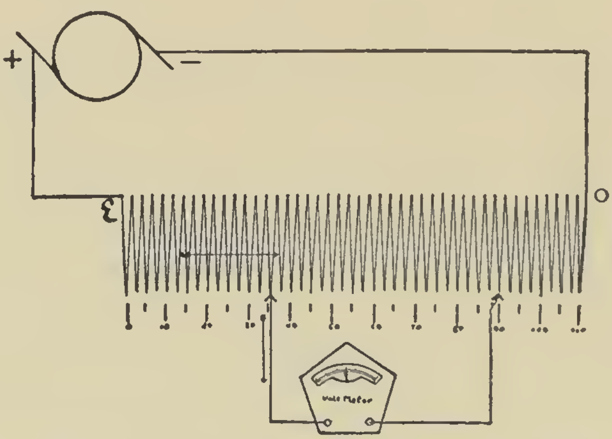

FIG. 113.—SHOWING METHOD OF REGULATION OF CURRENT BY PLACING RESISTANCE IN CIRCUIT.

able method for simultaneously reducing the voltage and the ampèrage of a current. Such **volt controllers** are made by the Wappler Electric Controller Company, of New York, and I have used them exclusively for two years without discovering a single defect in the principle or in their construction.

The mechanical arrangement of such controlling apparatus for the battery current can easily be deduced from the foregoing remarks; in describing the controllers for the electric-light current, it will become necessary to refer to them again.

A properly constructed water rheostat also presents many advantages, and when used in combination with the cell selector or volt controller and a battery current, leaves nothing to be desired

for therapeutic or diagnostic purposes. Especially can a current that is to be applied with great care and delicacy, as for instance to the head, be efficiently regulated thereby.

The carbon rheostats also are serviceable, so far as my experience goes, only when used with a battery current, and then, of course, not for scientific work. In the use of the street current they are decidedly unsatisfactory, and are so because their resistivity is greatly altered by the heat produced by this current, so that after a time they fail to accomplish the purpose for which they were designed.

Rheostats may be connected in two different ways: first, in the main, or, secondly, in a branch (shunt), circuit.

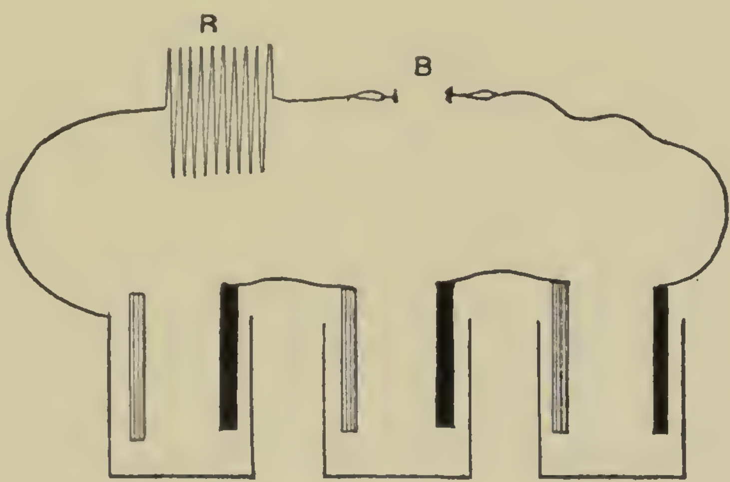

FIG. 114.—SHOWING A RHEOSTAT PLACED IN CIRCUIT.

The manner of connecting the rheostat in the main circuit is shown in figure 114. Here, of course, the more resistance, R, that is interposed,—that is, the more rheostat there is in the current,—the less current will flow through the body, B.

If the rheostat be placed in the branch circuit,—*i. e.*, shunted, as in figure 115,—it will be clear, according to the principles already explained, that two paths are open to the current: the one through the main circuit, in which the body is placed, the other through the branch circuit. The current always takes the path of least resistance, and as the human body possesses high resistance, the current, when the circuit is closed, will flow through the shunt,

and little or no current through the body. If, now, a rheostat, R, that possesses a higher resistance than the human body be introduced into the shunt, the current will flow through the circuit of least resistance—that is, through the body, B. It is, therefore, evident that the more resistance that is introduced in the shunt, the more current will flow through the body.

For the regulation of battery currents the rheostat should always be placed in the main circuit. Such rheostats must have a resistance of not less than 40,000 ohms, and one whose

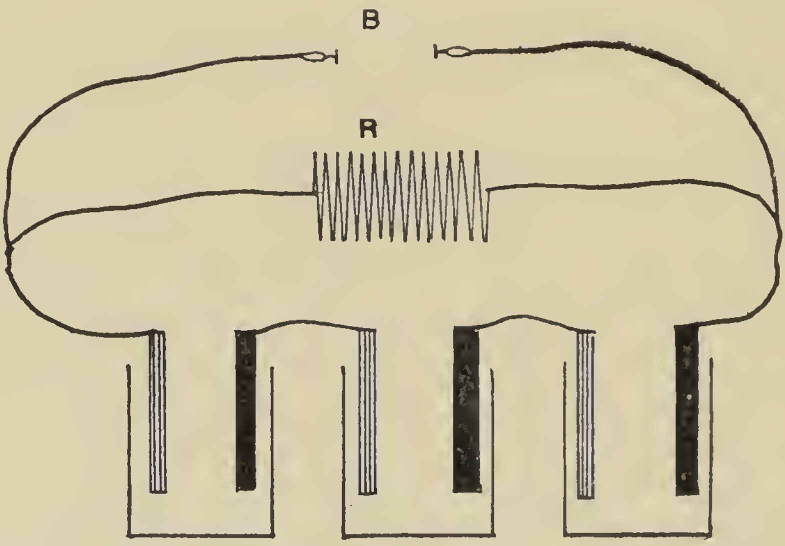

FIG. 115.—SHOWING A RHEOSTAT PLACED IN SHUNT.

resistance can be raised to 50,000 or even 100,000 ohms is preferable.

The reason why a shunted rheostat should not be employed in connection with a battery current is because a battery, to give good service, should have all connections arranged in as simple a manner as possible, and because the cells are unnecessarily used when a shunt is employed. The latter point is shown by the following:

If, for instance, with a current of 15 Leclanché cells 2 milliampères of current pass through the body, the shunt rheostat would require a resistance of 85 ohms, in which case 250 milliampères would flow through the shunt, so that the battery, instead of furnishing 2 milliampères, would have to furnish 252 milliampères, of

which only 2 are utilized. The following table clearly illustrates this loss :

3 ma.	through	body	require	300	ohms	shunt	R	=	100	ma.	through	shunt.
4 "	"	"	"	325	"	"	"	=	60	"	"	"
5 "	"	"	"	700	"	"	"	=	30	"	"	"
6 "	"	"	"	1400	"	"	"	=	15	"	"	"

It will be seen that this loss of current diminishes with the increase of current to be utilized. When, therefore, we desire to employ large currents, or when the internal resistance of a battery is high, this objection loses much of its force.

When we have an *unlimited supply of current*, as in currents from central stations, the arrangement of the *rheostat in the shunt* is the most practical, as such rheostats require a maximum resistance of not more than from 3000 to 5000 ohms, and thus become simpler and cheaper.

The **method of using the rheostat** is as follows : Beginning with the rheostat at zero, one selects, by means of the cell selector or volt controller, so much electromotive force as is desired for the individual case. He then gradually moves the resistance regulator, introducing resistance as slowly and regularly as possible, until the galvanometer needle indicates the figure representing the current that he desires, or, in electrodiagnosis, until a minimal contraction is obtained.

Current Interrupters, Reversers, and Combiners.

In the application of the dynamic current the necessity frequently arises for suddenly *breaking* and then again *making* the current, or for *reversing its direction*. The contingency is best met by effecting the desired change in the metallic part of the circuit, without removing the electrodes from the patient.

The mechanism by which the current can be broken and made at will is known as the **current interrupter** ; that by which the current can be changed and its polarity reversed is called a **current reverser** or **commutator.** It is most practical to combine these two mechanisms in one, so that by means of a current interrupter we can reverse, as well as break and make, the current.

A convenient **commutator** is made in the shape of two springs,

joined transversely and movable over three metal buttons. The mechanism of the instrument is shown in figure 116. If the springs are in the position indicated in the diagram,—A resting upon 2, B upon 3,—then A will be negative and B positive; if they are moved slightly, so that both A and B rest between the buttons in the position A′ and B′, the current will be interrupted; if they

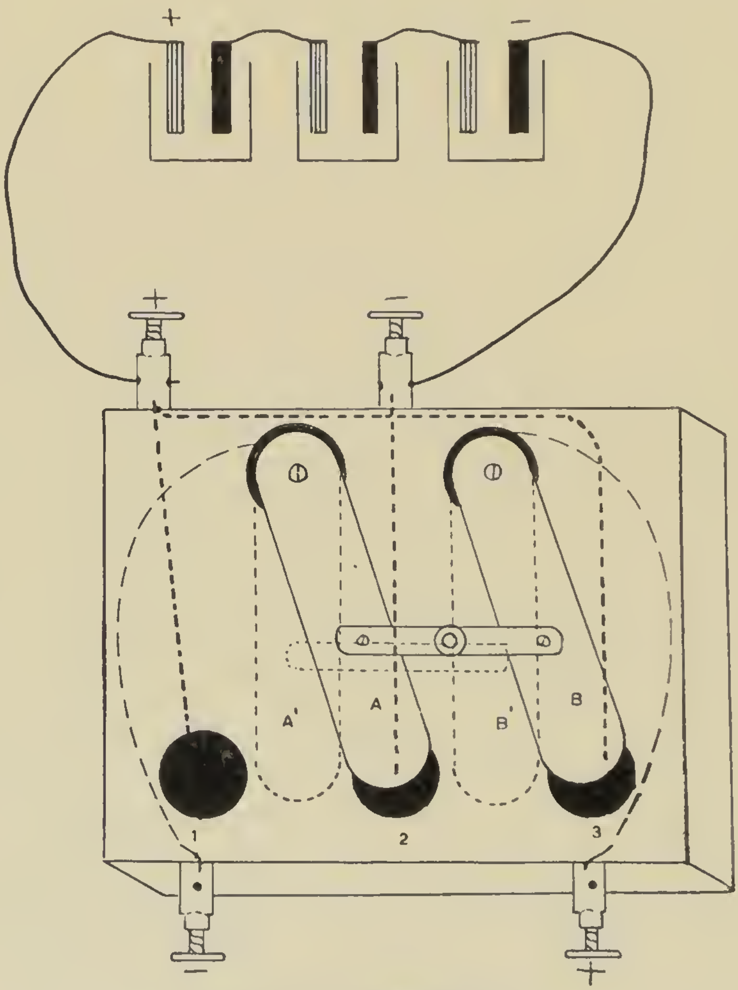

FIG. 116.—COMMUTATOR.

are moved to the other extreme, so that A rests upon 1, B upon 2, A will become positive and B negative, the current being reversed. Current reversers are manufactured in many different shapes; the principle, however, is always the same.

Galvano-faradaic Combiner.—It often becomes desirable in electrodiagnosis to be able to change rapidly from the galvanic to the faradaic current, and vice versâ, or in electro-

therapeutics to make use of these two currents in combination in the form of a **galvano-faradaic current.**

De Watteville has devised an instrument by means of which he facilitates the interruption and reversal of the galvanic current, as well as the use of the galvanic and faradaic currents alternately or in combination—*i. e.*, the galvano-faradaic current. The apparatus is made up of two reversers similar to the one just described in figure 116, and its mode of action and wiring is shown in figure 117. Two pairs of screws, G, F, receive connecting wires from the poles of the galvanic and faradaic apparatus respectively.

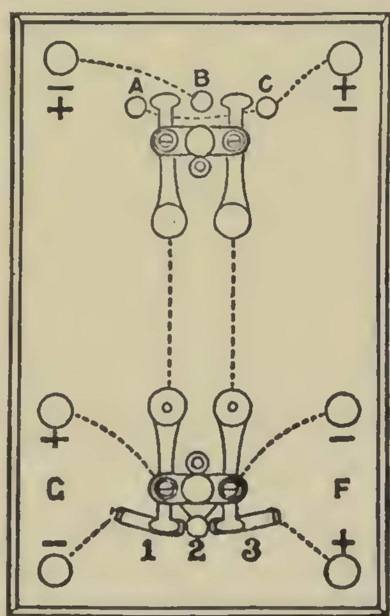

FIG. 117.—GALVANO-FARADAIC COMBINER.

When the springs rest upon 1 and 2, the galvanic current alone circulates; when upon 2 and 3, the faradaic; when upon 1 and 3, as in the diagram, the galvanic current passes through 2 to F—, thence through the coil to F+, to 3, and finally reaches + or +, to which the electrodes are attached, according to the position of the reverser; having traversed the body, it completes its circuit through the opposite half of the apparatus, G, and the battery. If the faradaic current is flowing at the same time, it passes through the same circuit. When all connections are made as in the diagram, the galvanic polarity of the electrodes attached to ∓ and ± may

easily be determined by remembering that the commutator A B C always points to the positive terminal.

Measurement of Current.

We have just seen that the strength of the galvanic current can be regulated in a variety of ways, and we also know that the strength of a current at any time can be measured by means of suitable instruments. Formerly it was considered sufficient if the measurement of the current strength was determined by the number of cells made use of or by the angle of deflection of the needle of a galvanoscope. It is, however, evident that such measurements possess no value whatsoever, as they are only relative and never absolute. Therefore some generally applicable system of measurement that would admit of an intercomparison of the results obtained by investigators at different places must be employed.

After a number of investigators, more especially de Watteville, had recommended the division of the galvanometers into units (millimeters, afterward milliampères), Gaiffe constructed the first so-called absolute horizontal galvanometer, and yet his instrument did not answer all requirements satisfactorily. When, however, Edelmann, in 1882, upon von Ziemssen's suggestion, constructed his unit horizontal galvanometer, he therewith furnished all future instrument makers with a basis for the construction of meters for medical work, and through this instrument the question, whether the currents employed in medicine can be measured easily and surely, is categorically determined in the affirmative.

Only magnetic measuring instruments are available for the measurement of currents used in medicine. In discussing the principles upon which these instruments depend we saw that they all consist of a movable magnet, and a current surrounding this magnet. We differentiate between horizontal and vertical galvanometers according to whether the movable magnet turns upon a vertical or a horizontal axis; in the latter the movable magnets swing in a horizontal plane; in the former, in a vertical one.

Any **milliampèremeter** that is to prove satisfactory for both diagnostic and therapeutic use must be constructed with the following desiderata in view:

The instrument must be of a low resistance. It must not be influenced by outside magnetism, and it must be independent of the action of gravitation. Its scale must be sufficient in extent (0–50 milliampères), and the divisions should be uniformly distributed over the entire scale and not crowded together at its end. The magnet should swing aperiodically, and the instrument should give equal deflection of the indicator to both sides of the scale, deflections to one side indicating the flow of current in one direction, deflections to the other side indicating the flow in the opposite direction. Instruments deflecting only in one direction are simpler in construction, and this fact counterbalances the slight inconvenience attached thereto. The instrument should indicate correctly in whatever position, horizontal or vertical, it may be placed. These remarks require certain amplifications.

1. Upon the low resistance of the instrument depends to a great extent its delicacy; this delicacy should, for diagnostic purposes, be such that $\frac{1}{10}$ of a milliampère will be indicated upon the scale, and $\frac{1}{100}$ of a milliampère may be estimated. For purely therapeutic purposes the measurement of $\frac{1}{2}$ of a milliampère is sufficient.

2. The instrument, in order not to be influenced by outside magnetism, and yet to be sufficiently sensitive, should have no iron, steel, or nickel constituent in its moving parts, and the permanent magnet should so be arranged around the core that all outside magnetism is neutralized.

3. The division of the scale to at least 50 milliampères would be impossible on a segment of a small circle, so that the use of shunts must be resorted to; thereby enabling us to measure certain known parts of the entire current. Thus, $\frac{1}{10}$ or $\frac{1}{100}$ of this current may be indicated upon the scale, in which case the scale divisions must be multiplied by 10 or 100 in order to obtain a reading.

4. In the instruments formerly employed, the magnetic needle oscillated to and fro for a long time before it came to rest. This in itself rendered the reading difficult, and often postponed a reading for so long that the reading, when made, did not correspond (on account of the lowered resistance of the body produced by the

flowing current) to the initial closure current that had produced a physiologic reaction. The manner of making an instrument aperiodic, or dead beat, has already been described.

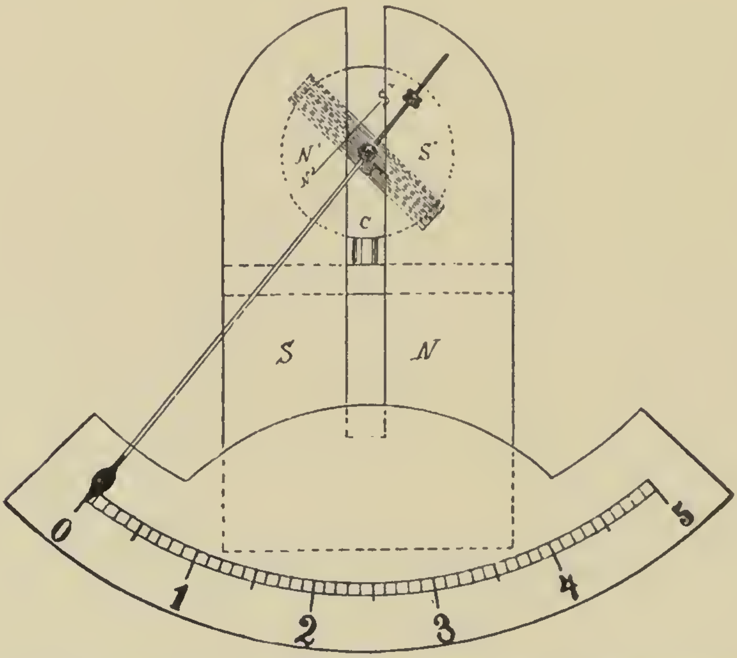

FIG. 118.—FRONT VIEW OF UPRIGHT MILLIAMPÈREMETER.

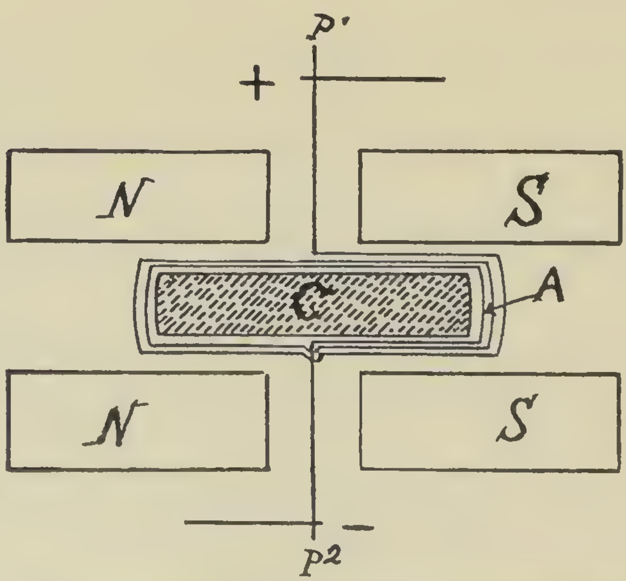

FIG. 119.—SHOWING TENSION SPRING OF MILLIAMPÈREMETER.

An excellent instrument, of American manufacture, serviceable for diagnostic work, and that possesses all the requisites stated,

except that the needle is deflected in one direction only, is made by the Wappler Electric Controller Company, of New York. The mechanism of this instrument may be understood from the accompanying illustrations. Figure 118 represents a front view. The permanent magnet *S N* consists of four pole pieces. A soft-iron core, *C*, is adjusted between the pole pieces at the point of greatest density of the magnetic field. An armature, *A* (Fig. 119), consisting of a small copper wire bobbin, swings in the magnetic field around the core *C*. The permanent field is adjusted to the field of the bobbin, N^2–S^2, so that the slightest direct current traversing

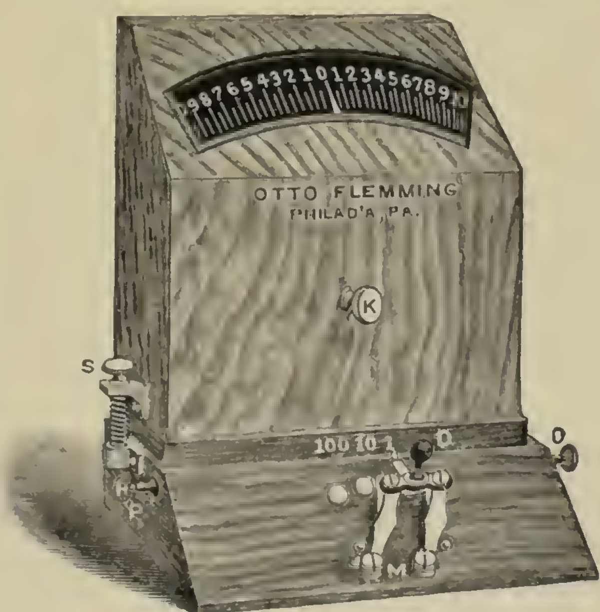

FIG. 120.—ANOTHER FORM OF UPRIGHT MILLIAMPÈREMETER.

the wire of the armature produces a tendency to rotate it. This rotary tendency is counteracted by two tension springs, P^1 and P^2 (Fig. 119), through which the current enters and leaves the armature.

Flemming, of Philadelphia, manufactures a milliampèremeter containing resistance coils by which the current may be lessened to $\frac{1}{10}$ or $\frac{1}{100}$ part, and in which the needle may be deflected in either direction (Fig. 120). It is approximately accurate, and with occasional readjustment serves a useful purpose.

Very convenient and reliable are the aperiodic horizontal milli-

ampèremeters devised by Eulenburg, and manufactured by Hirschmann, of Berlin. (See Fig. 121.)

Remarks on the Practical Choice of a Milliampèremeter.

Whoever desires to make use of a galvanometer for the purpose of obtaining measurements of currents for therapeutic purposes alone, and does not desire to make accurate measurements of quantitative physiologic reactions for diagnostic purposes, will have no difficulty in selecting a suitable instrument. A slight degree of inaccuracy is of no significance in electrotherapy, for the therapeutic

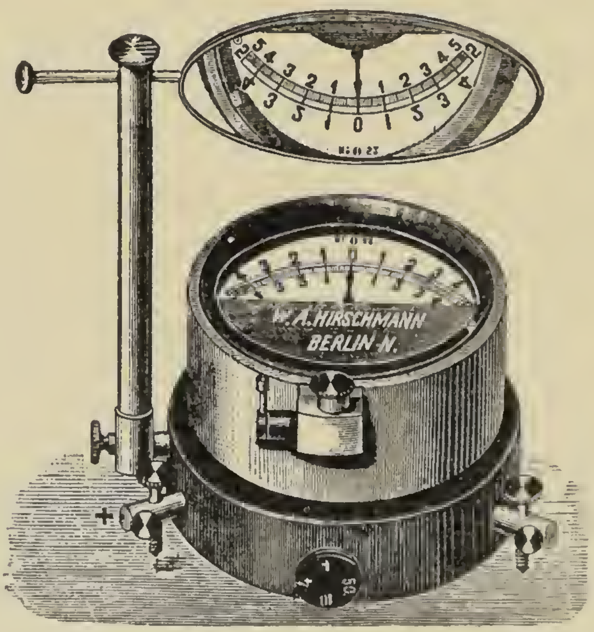

FIG. 121.—HORIZONTAL MILLIAMPÈREMETER.

action of a current is not altered by variations of ½ of a milliampère.

A vertical instrument presents the advantage of easier direct reading than does a horizontal one; on the other hand, vertical galvanometers with permanent magnets become unreliable in consequence of changes in the magnetism of the needles, and must, therefore, be recalibrated every few years. For ordinary practical use I find the advantages of direct reading over indirect reading by means of reflection in a mirror so great that I am willing to put up with the inconvenience of recalibration.

Whenever absolute accuracy, reliability, and permanency of calibration are desirable, the horizontal galvanometer should be selected. The best instruments of this type of which I have practical knowledge are the Weston meter, described on page 85, calibrated in milliampères, Hirschmann's instrument, and the one made by the Wappler Company.

Horizontal galvanometers with cocoon-thread suspension are not adapted for general use, on account of the trouble encountered in setting them up, and on account of the facility with which the thread becomes disordered or tears. Horizontal instruments with simple point suspension should be entirely discarded. The necessary wear and tear upon the suspension points rapidly renders them inaccurate.

Voltmeters.

It becomes more and more apparent, especially in electrodiagnostic and electrophysiologic experiments, that the **regulation of the voltage** of a galvanic current is of greater importance than the regulation of current strength by means of interposed resistance. The arguments that for years have been advanced in favor of the use of an absolute meter of the current strength employed in medicine, and that have forced its universal adoption, may be applied, *mutatis mutandis*, to the use of a meter for determining the pressure of the current employed; and there is no doubt in my mind that in a very few years the use of a **voltmeter** by physicians and physiologists will be quite as universal as is the present use of the galvanometer.

The principles underlying the construction of voltmeters have already been stated. If the resistance of a milliampèremeter be increased up to 1000 ohms, it can, without further change, be used to measure electromotive force, for as a current of one volt produces one milliampère in 1000 ohms, the milliampères are equal to the volts so long as the resistance in the circuit is 1000 ohms.

Any galvanometer of sufficiently high resistance may, therefore, be calibrated in volts and be used as a voltmeter. In the use of the voltmeter neither the body of the patient nor any other unknown

resistance must be in the circuit while the electromotive force of the source is being measured.

Reliable voltmeters are made by all manufacturers of industrial electric instruments. The Weston and the Jewell meters are those that I know best. The Jewell meter is manufactured by the McIntosh Battery Company, of Chicago, and is shown in figure 122. This meter is made according to the principles here advocated, with a coil moving in the field of a permanent magnet. It

FIG. 122.—JEWELL VOLTMETER.

has a resistance of about 120 ohms to each volt of scale, so that a meter capable of registering from 0 to 150 volts has a resistance of 18,000 ohms.

Electrodes.

For the application of a current to the body for diagnostic or therapeutic purposes, specially adapted end-pieces, or **electrodes,** are necessary. These may be made of various materials and shapes, according to the place of application for which they are designed. For all purposes that require uniformity of application and pressure,

the electrode is furnished with a handle; in such cases the material that constitutes the electrode must be sufficiently rigid not to bend when pressure is exerted, and therefore only a hard metal should be used. Yet their rigidity may be regulated by the thickness of the metal employed, so that if it is desirable to give them an individual shape for certain purposes, this may be done by using a metal sheet that is so thin that it is capable of being bent by hand, but that is yet of sufficient firmness to retain the shape that has thus been given it, despite a fair degree of pressure exerted on it through the handle.

Electrodes that are to be applied to the body directly by the hand of the operator or by means of a broad band may be made

FIG. 123.—ELECTRODE HANDLE.

FIG. 123 A.—ELECTRODE HANDLE.

of flexible metallic lead, amalgam of tin, or wire netting, and thus adapt themselves more easily to the surface of the body. The handle of the electrode may be made the carrier of various contrivances for making, breaking, and reversing the current or for controlling it. This handle is made of some insulating material, usually hard rubber or wood, and should be so formed as to be grasped easily. Into the end of the handle is fixed a metal piece bearing a binding screw and a metal rod, to which the electrode is fastened, or the metal rod bearing the electrode at one end may be made to pass through the insulating handle and have its binding screw for the attachment of the conducting cord at the other end. Figure 123 shows the first form of handle and figure 123 A the second.

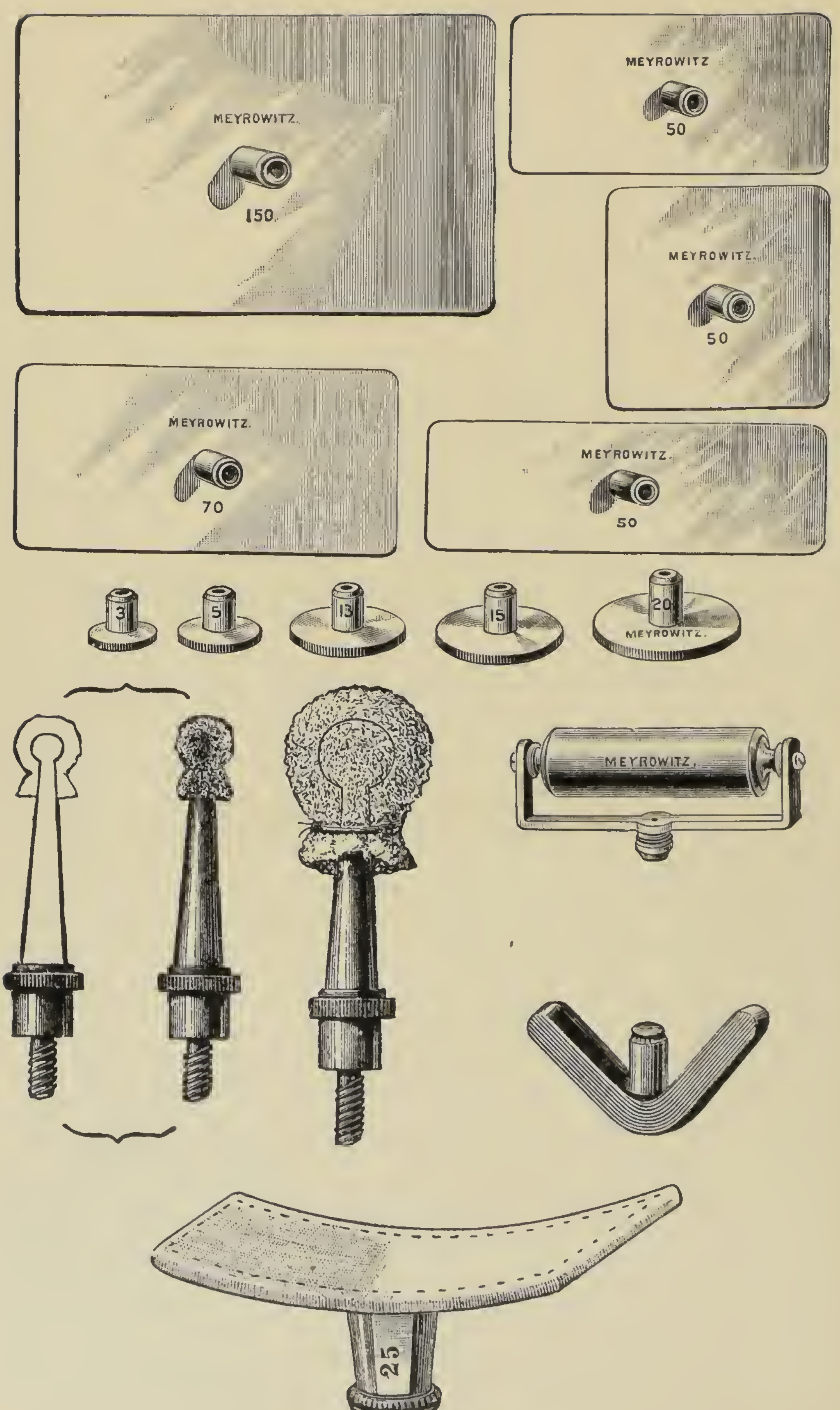

FIG. 124.—VARIETIES OF ELECTRODES.

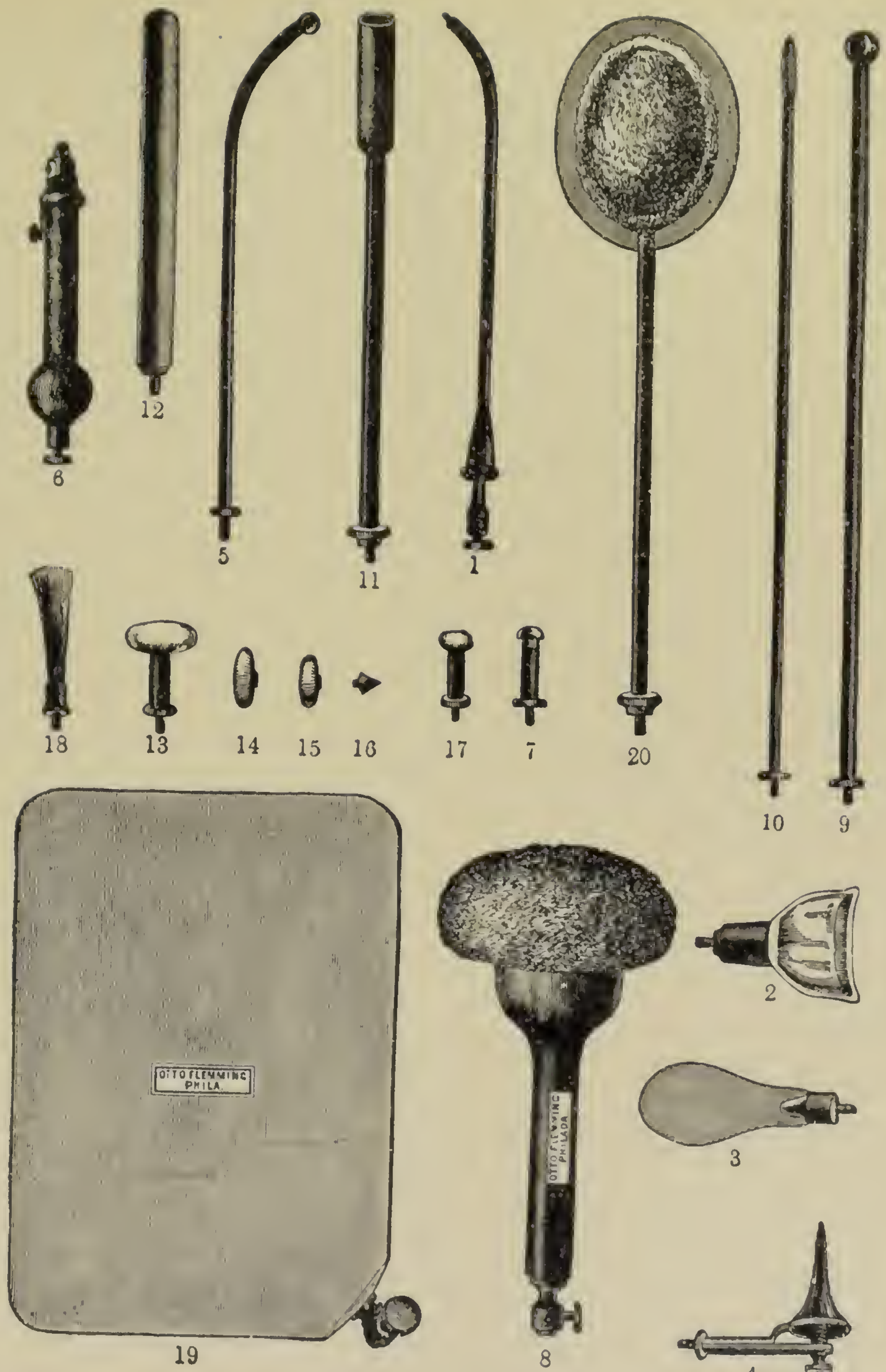

Fig. 124 A.—Interrupting Handle and Various Electrodes.

1. Eustachian. 2. Eye. 3. Tongue. 4. Ear. 5. Nasal or laryngeal. 6. Interrupting handle. 7. Special nerve. 9. Uterine and rectal. 10. Urethral. 11. Cup-shaped for os uteri. 12. Vaginal. 14, 15, 16. Olives, points, etc. 17. Carbon disk. 18. Wire brush. 19. Foot-plates. 20. Spinal.

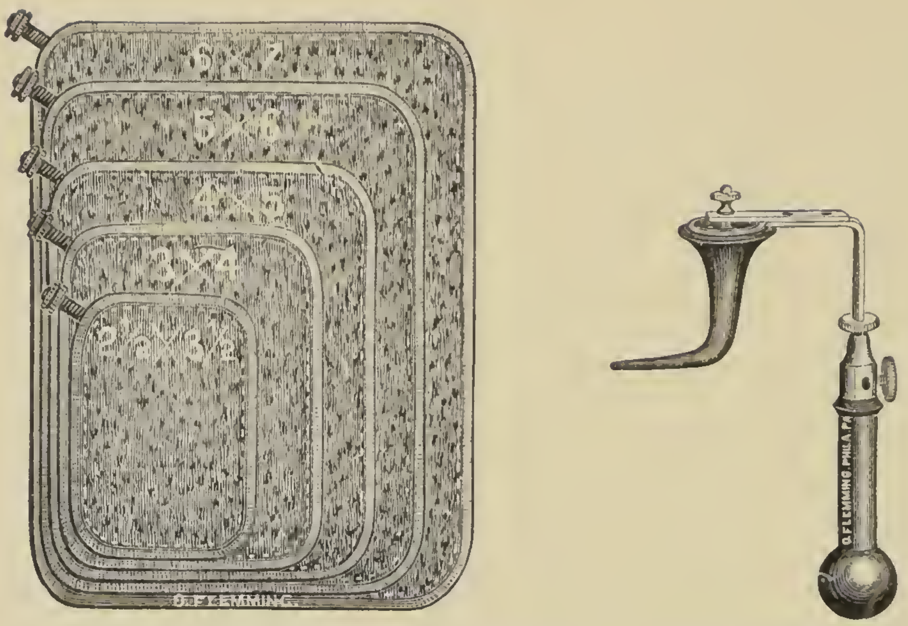

FIG. 124 B.—ABDOMINAL AND OTHER PADS. AURAL ELECTRODE.

The electrode itself may be made of various forms, flat and in that case circular, square or oblong, ball shaped or conic ; be made of metal or carbon ; and be bare or covered. If bare, it is used as a dry electrode ; if covered, it is covered permanently or at the time of application with sponge, cotton, clay, or other material that may be saturated with water, and is used as a moist electrode. Cotton is easily wrapped about the carbon or metal terminal of an

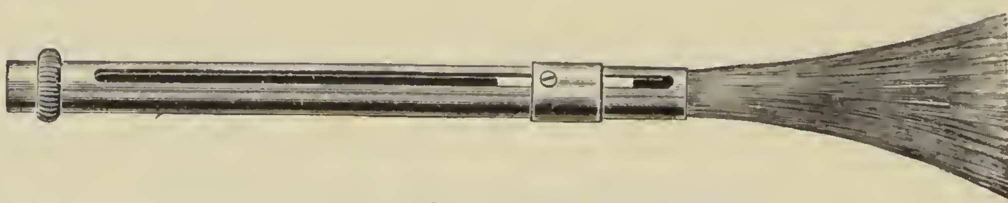

FIG. 125.—WIRE BRUSH ELECTRODE.

electrode, and as this may be freshly done each time the instrument is used, makes a very cleanly covering.

Electrodes of various shapes are shown in figures 124, 124 A, and 124 B. Figure 125 shows a bare electrode consisting of wires of brass or metal bound together in the form of a brush. It is known as a wire brush. An assortment of such electrodes, varied not only in form, but also in size, should form part of every electro-diagnostic and electrotherapeutic outfit. The flat electrodes should

have the area of their covered surface marked upon them. Ball electrodes should be supplied in diameters of 1, 2, and 3 cm. when covered.

In the application of electricity to the surface of the body, electrolytic action takes place in the parts of the body traversed by the current; the alkaline constituents of the decomposed tissue fluids accumulate at the negative electrode, the acid constituents at the positive electrode. These products of decomposition act deleteriously upon the skin, and alter the electrode itself so as to interfere with accurate scientific investigation. For these reasons the exclusive use of unpolarizable electrodes was recommended by the Paris International Congress of 1881. This recommendation is too far-reaching, but must be subscribed to in so far as scientific investigations and persons with susceptible skin are concerned. It is always necessary, however, to give due regard to the coverings

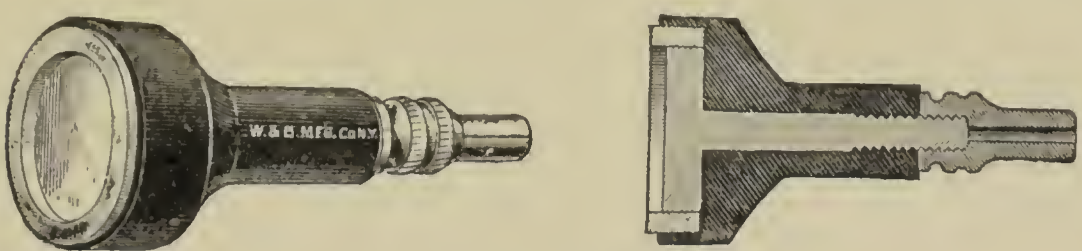

FIG. 126.—UNPOLARIZABLE ELECTRODE.

of the electrode, to see that they are clean and not worn, and, above all, to be careful that no metal part shall come in direct contact with the skin.

An **unpolarizable electrode** is shown in figure 126. The detachable handle carries a bell glass, into which protrudes a zinc rod that is metallically connected with the binding screws. This bell glass is filled with a solution of zinc sulphate, and is closed by means of a stopper of clay or papier-mâché enveloped in two folds of linen.

The direct application of electricity to the various body-cavities is effected by specially constructed electródes. Their number is so great that it is unprofitable even to mention them all, much less shall we attempt to give a description of them.

The **handle** is best made detachable from the electrode itself,

and it then possesses the practical advantage that one handle can be utilized for many attachment pieces. The attachment mechanism between handle and electrode usually consists of a screw and nut, the one or the other being upon the handle or upon the end of the electrode. This variability in construction, as well as the fact that different screw-threads are used by different manufacturers, often renders it impossible to utilize the handle for any but the electrodes

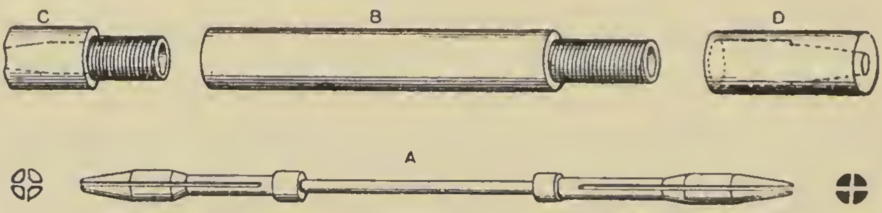

Fig. 127.—Combination Electrode Handle.

made by the manufacturer of the handle. To obviate this difficulty I designed, many years ago, a **combination handle** that admits of the use of any electrode having a metal attachment end, entirely regardless of the size or construction of this end. This handle is shown in figure 127. It consists of a double workman's chuck, A, inserted into a hard-rubber cylinder, B, to the ends of which are screwed small cylinders, C and D, beveled longitudinally upon their interior. Through these the metal chuck also passes.

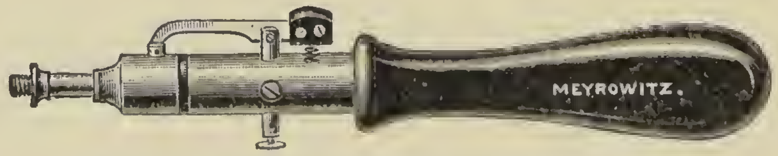

Fig. 128.—Interrupting Electrode Handle.

The further the cylinders C and D are screwed down, the more do the chuck ends become compressed, and the smaller does the opening become. The method of use of these handles is first to loosen the end cylinders until the openings in the chuck are sufficiently large to admit of the introduction of the end-piece of the electrode at one terminal, and the binding piece of the conducting cord at the other; then the cylinders are screwed down until the inserted electrode and conducting cord are firmly held.

The handle, as already mentioned, may also be made the carrier of a current interrupter, reverser, or controller.

The **interrupting electrode** that I consider the best is shown in figure 128, and a new and practical pole-changing and current-controlling electrode, made for me by the Wappler Company, is shown in figure 129. Both these illustrations explain themselves.

Usually, in electrodiagnostic and electrotherapeutic work it is desirable to attach one electrode firmly to the body of the patient, so that while manipulating the other the operator may have a free hand for the regulation of the current, etc. Such fastening may be accomplished by means of an elastic belt or by means of hard-rubber springs. The latter possess the advantage that,

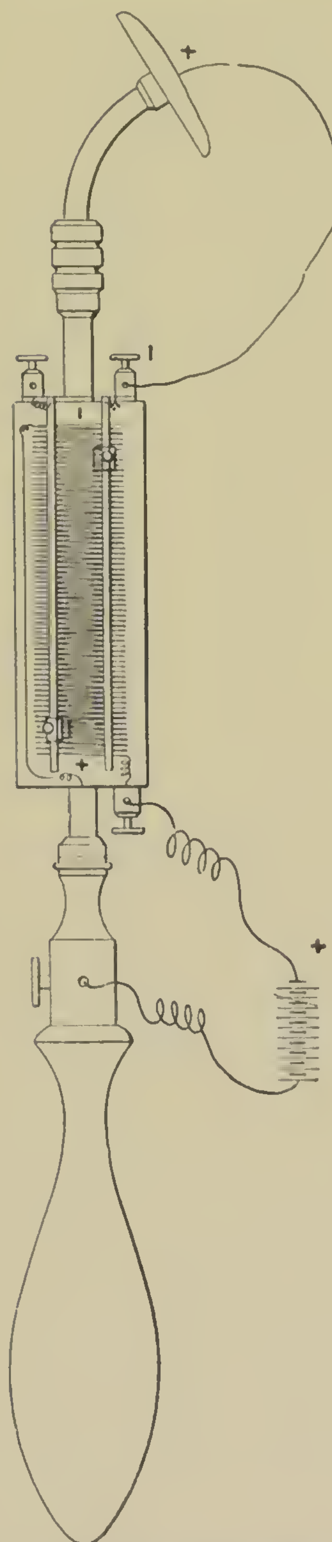

FIG. 129. — POLE-CHANGING AND CURRENT-CONTROLLING HANDLE.

FIG. 130.—ELECTRODE WITH HARD-RUBBER SPRING ATTACHMENT.

FIG. 131.—ELECTRODE WITH ELASTIC BELT ATTACHMENT.

by means of heat, they may be given any desired shape or strength of spring (Figs. 130 and 131).

Conducting Cords.

Conducting cords are used to make a connection between the electrode handle and the source of current supply. They consist of a conducting wire or wires covered with some insulating material, and are furnished with rigid metal ends by means of which they may be firmly connected with the binding posts of the battery. Such a conductor should be made up of a cable of many copper or brass wires, and be so flexible that the entire cord presents no inconvenience on account of rigidity. Their length should be at least 1½ meters, and the insulating coverings should be of different colors—red and green or red and black—for the two cords employed, so that they can easily be followed by the eye from the electrode to the battery, and thus the pole of the electrode be recognized.

CHAPTER III

SOURCES OF CURRENT SUPPLY FOR DIAGNOSTIC AND THERAPEUTIC PURPOSES, AND THE APPARATUS NECESSARY FOR ITS USE

Requirements of Stationary and Portable Batteries. Different Types of Cells. Pole Testers. Care of Apparatus. Causes and Remedies of Disorder. Currents from Central Stations. Direct and Alternating Currents. Dangers of High Voltage Currents. Leakage Currents. Controlling Apparatus. Transformed Systems. Breakdown of Insulation. Safeguards. Sudden Increase of Current. Compound Shunt. Method of Using Street Currents. Limit Resistance. Rheostat. Author's Method.

APPARATUS.

The prime essentials of an apparatus for electrodiagnostic and electrotherapeutic purposes are as follow: The source of supply must have a sufficient electromotive force and be of fair constancy; a current controller, preferably a selector or volt controller and rheostat, a pole changer, and a galvanometer must be available in the circuit.

The source of supply may be from a central station (electric light, etc.) or from a battery. Over the currents supplied by the electric light and power companies the physician has no direct control. He can modify them only after they reach his apparatus. Considerations of various kinds, however, may govern the choice of a battery.

Batteries and Cells.

In addition to being fairly constant and furnishing a current of sufficient intensity the battery should be durable, and at the same time of such simple construction that all its parts are readily accessible and can be kept clean and in repair by the physician himself; furthermore, the original cost, as well as

the cost of maintenance, should be moderate. The frequent necessity of transporting the apparatus to the patient's bedside requires that one form shall be small, light, and easily portable.

The **electromotive force** of the battery must be sufficiently great to furnish 20 milliampères against a resistance of 5000 ohms. For certain special purposes from 3 to 5 milliampères may suffice, while for others (gynecologic work) many more are necessary. Theoretically, we should therefore prefer cells of high electromotive force and slight internal resistance; but considering the high resistance of the human body, this is not essential, and cells with less surface of elements, and which, therefore, are smaller and have a higher internal resistance, such as the Leclanché, will, for other reasons, be found more efficient. In order to obtain sufficient current strength a battery must be made of a large number of cells. **Stationary batteries** with Daniell cells require at least from 50 to 60 cells, while if Leclanché cells be used, 40 will suffice. A **portable battery** should have 40 Leclanché or silver chlorid cells, or 30 potassium bichromate cells.

As regards the **constancy** of the battery, it is necessary that, with an interposed resistance equal to that of the human body, the current strength should remain unaltered for at least fifteen minutes. This may be taken as the maximum service required of a battery at any one time, while usually a very much shorter period will suffice, and in electrodiagnosis momentary currents only are required. For this reason, and because by means of a proper system of current control and a milliampèremeter the current can always be kept at a certain strength, no matter how inconstant a battery may be, I lay less stress upon the constancy of the battery than is usually done.

For **portable batteries** the cells will, of course, be as small as possible, leaving all other qualities aside, and for this reason such cells as the Grenet and dry cells, which would be unfit for use in a stationary battery, may here be used.

Stationary batteries, on the other hand, must, above all, be durable and reliable, while the size is of less importance. Therefore other qualities of the individual cells may be considered.

So, in a portable battery, the current controller and reverser may be affixed to the electrode handle and the galvanometer be detachable from the apparatus, while in a stationary battery all these appliances should form an integral part of the machine, as it will also be found practicable to combine the **faradaic coil**, as well as any other apparatus (**sinusoidal**), on one and the same base with the other parts of the apparatus.

Cells.

The choice of a cell will depend upon the purpose for which it is to be employed—whether for a stationary or for a portable battery, and whether the current is to be directly applied to the body or is to be used for cautery and light.

Any cell of fair electromotive force and constancy may be employed for diagnostic and therapeutic purposes; yet certain cells possess material advantages over others.

For **stationary batteries** the gravity cells have been largely used, but in my opinion they are entirely unsuited for the practical requirements of a physician. They are exceedingly dirty, in consequence of the constant accumulation and creeping of the zinc sulphate, and the frequency with which they must be refilled makes them untrustworthy. Evaporation rapidly breaks the circuit by lowering the water surface below the horizontally suspended zinc. The cells best suited for a stationary battery are of the open circuit type, and of these, the one that I have found most advantageous is the Leclanché, of one form or another, either the prism or gonda pattern. For all-around work—galvanization, electrolysis, etc.—I know of no cell that will give so much satisfaction. Its electromotive force is high, and its internal resistance is moderate.

So long as the cell is not in action there is little chemical decomposition, as the circuit, then, is open. Theoretically, there should be none. The cell is always ready for use, and if well constructed, will last for some two years without other attention than an occasional refilling with water. These cells, furthermore, are so simple and so easily managed that they may be cleansed and refilled without expert assistance.

Portable Batteries.—Highly as Leclanché cells are to be rec-

ommended for use in stationary batteries, they give little satisfaction for portable use. This results from their necessary diminution in size. The smaller such a cell is made, the more unsatisfactory does it become. Test-tube Leclanché cells have been combined into portable batteries, but their constancy is so problematic and their local action is so great, that such batteries give no satisfaction at all.

Dry cells (really an improved form of Leclanché) are quite desirable for portable batteries, on account of the impossibility of spilling and oxidation. Such cells, if not too small, are sufficiently constant for all medical purposes, and, having a capacity of as much as 4 ampère-hours, would last for 4000 applications of 6 milliampères of current and of ten minutes' duration each. The only objection to such batteries is from an economic point of view; for the cells once exhausted, cannot be replenished, but must be replaced by new ones.

When a specially small cell is required, or whenever the restriction of the size of a battery to a minimum is desirable, there can be no better selection than the silver chlorid cell. Such cells are most thoroughly depolarizing, and can, therefore, be made smaller than any other without sacrifice of constancy. They have an electromotive force of 1.61 volts, and a low internal resistance; they are always ready for use, are not in action when the circuit is open, and are so sealed that no fluid can escape by shaking or with moderately rough usage. The objection to these cells is the expense of refilling.

Potassium bichromate cells possess certain advantages for portable batteries that make their use desirable, especially for country work, where the services of an electrician are not usually obtainable, and for those who have but infrequent use for a battery of any kind. In the first place, they can easily be refilled and cleansed by the inexperienced; such a battery that has stood unused for months may be cleansed, refilled, and put in good working order again in about one hour. Furthermore, they have a very high electromotive force—2 volts—and less than 0.05 ohm of internal resistance, so that two cells are about equal in practical medical work to three cells of the Leclanché type; thus the bat-

tery may be considerably smaller. They are also particularly useful for the strong current required for electrolysis. The zincs last for a number of years when used only for average bedside work, and can be replaced easily. Various solutions may be used as electrolytes. The preferable solution is the following:

Potassium bichromate,	1 part
Water,	20 parts
Strong sulphuric acid,	2 parts
Mercury bisulphate,	1 part.

To cleanse the cells, the vessels should be filled with water, and the elements should be left to soak in them overnight, so as to dissolve all the crystals that may have formed. The disadvantage of these cells is that they must have plunge elements, and the mechanism by which the plunging is effected frequently becomes disordered. The vessels cannot be closed effectually, and in consequence evaporation and spilling of the fluid are not guarded against. If the battery is in daily use, it must be cleansed and refilled about once in every three months.

The purpose for which the cells are to be used will determine the manner of their arrangement.

The number of different kinds of stationary and portable batteries manufactured for medical purposes is very large, and each one may have some special point in its favor. It is, however, impracticable and useless to enumerate the various kinds in the market, as the principles governing their construction have been given at ample length. The catalogues of manufacturers may be consulted to determine in how far these principles have been carried out.

Tests for Polarity.

The cells having been arranged into a battery, the terminals of the first carbon and that of the last zinc must each be joined to a binding post upon the plate of the apparatus used. These binding posts then become the positive and negative poles respectively, and serve for the reception of the ends of the conducting cords. These poles are usually marked + and —, but often, through some error of connection, the polarity has become changed or the posts may have been marked incorrectly; it is,

therefore, necessary to test the polarity of the posts before using the battery. The poles of the battery may be determined as follows: The two metal ends of the terminal wires being placed upon a piece of moistened litmus paper, the anode will turn the paper red, while the kathode gives it a deep blue color. If instead of litmus paper a mixture of potassium iodid and starch paste is used, the anode causes a deep blue coloration.

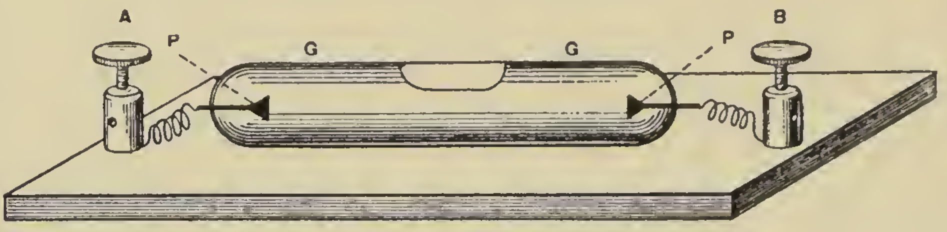

FIG. 132.—POLE TESTER.

When a great deal of pole testing is to be done, as when the current is obtained from the main (because the dynamo may at any time be reversed without our knowledge), it is convenient to have a special **pole tester.** I have had constructed two that are admirable in their simplicity and trustworthiness. The testing agent here employed is phenol-phthalein. One of the devices consists of a glass tube filled with a solution of phenol-phthalein and sealed.

FIG. 133.—POLE TESTER.

In each end of the tube is a piece of platinum wire that passes through the glass into the fluid, while the outer ends are connected with binding posts (Fig. 132). The fluid surrounding the kathode turns a bright red upon passage of the current. The agitation of the liquid causes the red color to disappear.

In the other device, figure 133, a paste of chalk, plaster-of-Paris, and phenol-phthalein is held in a form of hard rubber.

For use the paste is slightly moistened and the wires are applied, when the red color at once indicates the negative pole.

When none of the foregoing indicators is available, the wires may be placed in a glass of water, and the large number of bubbles arising from one wire will indicate the positive pole; or the electrode may be applied to the tongue, when a weak alkaline taste will indicate the kathode, a markedly acid one, the anode. In neither of these methods should a strong current be used.

Care of Battery.

No matter how well constructed, every electric apparatus requires a certain amount of care and attention. The physician who knows thoroughly every detail of the mechanism of the apparatus with which he is working, being able, if necessary, to take it apart and put it together again, will derive more satisfaction from an inferior apparatus than will he who does not possess this knowledge obtain from one that is actually much better in every way. Simplicity of construction is, therefore, a great advantage; the fewer screws, wires, and connecting points there are, the more readily will the physician be able, in an emergency, to repair slight disorders of function, and the less likely are such disorders to take place.

Location of Disorder.—Should disorder occur and the current grow suddenly weak or fail entirely, the source of trouble should at once be sought. It has been my experience that in the majority of cases imperfection or failure in the current flow is due to disordered contact at some point of the circuit. Hence a systematic search should be made, and the entire circuit be examined.

It is best to begin with the connection between the body of the patient and the battery, then to examine the instruments upon the base of the apparatus, and finally to inspect all connections under the base and in the source of supply itself. It will most often be found that (1) the electrodes are not sufficiently moistened, and that, on account of insufficient contact between electrode and body, the necessary amount of current cannot pass. The remedy is obvious—viz., thorough saturation of the covering of the

electrodes, preferably with warm or salt water. (2) There may be a break in the wire of the conducting cords. Such breaks usually take place at the part where the wire is attached to the insertion piece of the cord; a break may also occur within the insulating covering. A test made after the removal of the insertion piece or the substitution of the entire cord by another, and notation of the galvanometer deflection, will show the seat of trouble if it lie in the two cords.

If no disorder be found in electrodes or conducting cords, the apparatus on the base must be scrutinized. Here the most frequent disorders are: (1) The loosening of a screw; therefore all screws should be tightened. (2) Switches, contact buttons, plugs, and plug holes become tarnished, corroded, or dusty, and thus interfere with perfect contact. A little vaselin or oil will remedy this. (3) The galvanometer is frequently connected to the base by means of a metal spring, and this connection may have become loosened. (4) The faradaic current usually fails because the interrupter works badly. Usually it does so because the contact between the screws and contact plate has become deranged. A proper adjustment of the screw will remedy this. Or it may fail because the contact plate has become oxidized, in which case the oxid may easily be removed with a file.

No disorder having been found above the base, an examination of the cells and their connections should follow. Here the disturbance will usually be found in the cells themselves. Such disturbances are due to lack of water surrounding the elements, or to the zinc being so badly eaten that it must be replaced.

Any disorder in the wire attachments of the cells can be remedied easily.

CURRENTS FROM CENTRAL STATIONS.

Whenever a current from a central station can be obtained,—that is, whenever electric wires for lighting or power are easily accessible,—the physician can well dispense with the always more or less troublesome and inconvenient cells, and obtain all the advantages of an unlimited supply either by using such currents

directly or by charging secondary (storage) cells and then deriving his therapeutic or diagnostic current from these.

Dynamo Currents.

At first impression it seems foolhardy to use for medical purposes an electric current that has caused so many and so serious accidents. The convenience of this source of electricity is, however, so great that if it can be shown that the dynamo current can so be regulated that its employment will be unattended by danger, every physician who has access to such a current will undoubtedly desire to use it.

The current that is easiest to use is the one employed for lighting incandescent lamps, as that is furnished directly to all modern houses.

For lighting lamps both direct and alternating currents are employed.

The **direct current** dynamos deliver a current that, to all intents and purposes, is constant,[1] and that practically differs in no way from a battery current. It will serve fully the purposes of the physician.

The **alternating current,** on the other hand, is lacking in electrolytic quality, and requires a transformer for cutting down the voltage, and a commutator for turning the alternating current into a unidirectional one before it can be made available for our purposes.

In New York city, the direct current delivered to us is the **Edison current,** which is received at a pressure of 110 volts approximately. It is this current to which reference is had here unless some other is specially mentioned. In considering the physical laws governing this current, all that has been said concerning battery currents will apply, except that, inasmuch as we have no internal resistance to deal with, we can, from our 110 volt source of supply, obtain an extremely strong and intense current if little resistance be placed in the circuit, and it need hardly be said that by interpos-

[1] Ample experiments have been made, proving that nothing need be feared on account of the inconstancy of the current, as is shown by the steadiness of the galvanometer needle.

ing sufficient resistance we can prevent any current whatever from passing.

We therefore see that the regulation of our current is practically entirely a question of interposed resistance.

Before proceeding with the description of the apparatus used for control of the current pressure and current quantity, let us directly answer the question that is asked daily: Is there no danger in the use of an electric-light current? *There certainly is.*

Any uninsulated conductor through which the current is passing may be held in the hand without other danger than is due to the overheating of the wire. If, however, the current be one of high voltage, and a complete circuit, of which the body forms a part, be thereby established, there may be grave danger to life in grasping such an uninsulated conductor.

Thus, a person standing upon a dry wooden floor may with safety touch a bare wire through which a current of high voltage is passing, and will in all probability not be aware of the fact that an electric current is flowing; if, however, this person, while touching the bare wire, should bring any other part of the body into contact with some other electric conductor, as a gas-pipe, a water-pipe, or a grounded wire, he may receive an injurious and even a fatal electric shock.

The quantity of current that, under these circumstances, will pass through the body depends, of course, not only on the electromotive force of the source, but also on the resistance of the circuit—that is, the body; and this resistance will be dependent upon the nature of the contact between the body and the other conductors. It is, therefore, not possible, even with a given electromotive force, to say whether a strong or a weak current has passed through the body, unless we know whether good contact or poor contact has been made. As regards the voltage that may, under favorable circumstances, prove dangerous, we may say that a continuous electromotive force of twenty volts cannot prove injurious when applied to any part of the uninjured surface of the body, because from this pressure only a small quantity of current can thus be obtained.

Kennelly, in experimenting upon animals, has shown that an al-

ternating electromotive force of fifty volts is capable of killing a dog in two or three seconds when suitably applied by means of large electrodes; and from his experiments upon dogs, horses, and cows it seems that with currents of ordinary commercial frequency the danger from a certain alternating pressure is two or three times as great as that from the same amount of continuous current pressure. The danger in New York and other large cities, with their subways and perfected source of supply, does not lie, as is generally assumed, in the sudden increase of the current strength or in the failure of supply. The actual dangers against which we must guard lie, as Hedley has shown, in leakage currents, and, when the alternating current is employed, also in the breakdown of insulation between primary and secondary transformers.

The first source of danger has been underestimated or completely ignored by all writers, with the exception of Hedley; nevertheless the danger is a menacing one, and may give rise to serious accident. In order to understand these accidents let us see how the direct current is distributed to the consumer in New York. This is done by the three-wire system.

This system consists of a double circuit, each branch of which has an electromotive force of 110 volts, the entire circuit thus giving 220 volts. This division is made for purely practical purposes, inasmuch as 220 volts will carry a larger quantity of current a longer distance with a smaller percentage of loss than 110 volts will.

In this double circuit the middle or neutral wire leads to the ground, or is, perhaps, contrary to law, even grounded. The accompanying diagram (Fig. 134) shows the wiring of such a 220 volt circuit.

Inasmuch as all water- and gas-pipes are underground, the neutral or ground wire may prove a source of danger by carrying an excessive amount of current into houses through these gas- and water-pipes, as they actually form branches of the neutral wire that are free in the rooms at all outlets—*i. e.*, gas-jets, chandeliers, bath-tubs, and faucets. This danger is shown in the following diagram (Fig. 135).

It will be seen that the neutral wire G is connected, through the

earth, with faucets and gas arms, and certainly also with waste-pipes. Now, if the rheostat or current-regulating device is connected between the one terminal, A, leading to the patient, and the wire G in the diagram, we can plainly see that if the patient should in any way form a ground connection, through a damp floor or through a bath-tub with a waste-pipe attached, or by coming in contact with

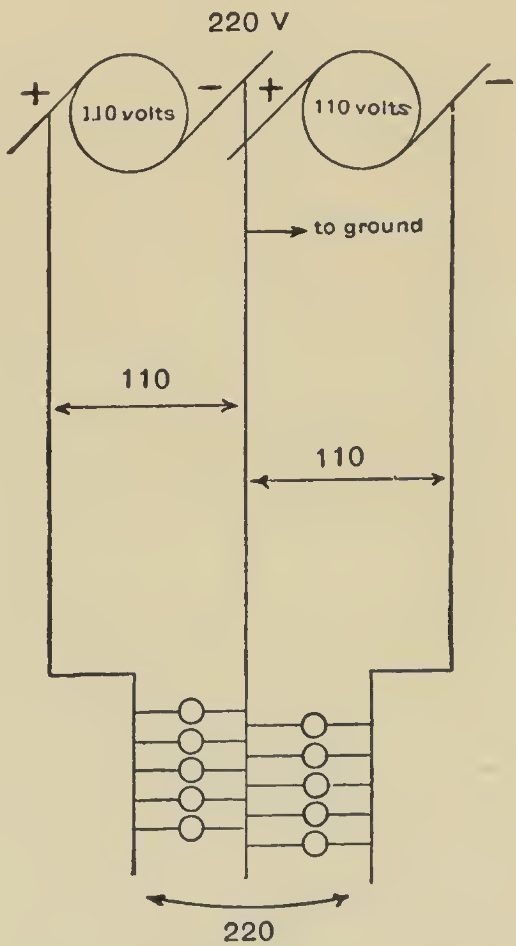

FIG. 134.—DIAGRAM SHOWING THE ARRANGEMENT OF WIRES IN THE 200 VOLT CIRCUIT.

a gas arm or water faucet, the rheostat would become useless, as the current would take the course of least resistance and pass from the ground through the patient to the positive wire, thus giving the patient the full voltage (110 volts) on the line.

It is thus apparent that there is danger connected with the use of the current unless the right wires are selected first and an efficient controlling apparatus put in the proper place. The correct manner

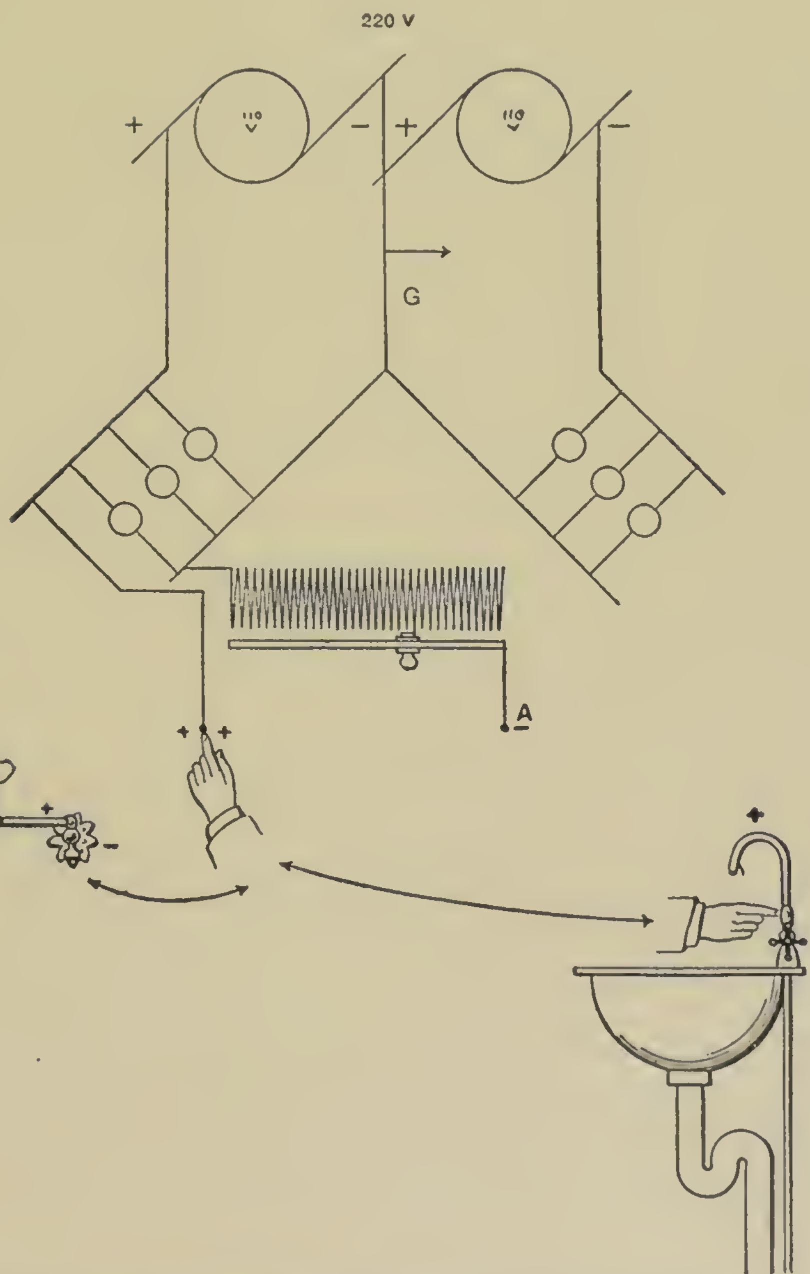

Fig. 135.—Diagram Showing the Danger of the Three-wire System.

of introducing the **controlling apparatus** is shown in figure 136. It will here be seen that the resistance is placed between the main branch of the circuit and the patient, so that if the patient come in contact with a grounded pipe, the resistance will still be between him and the source of current.

A source of danger, which can, of course, occur only with **transformed systems,** is that due to a breakdown in the insulation between the primary and secondary windings of a

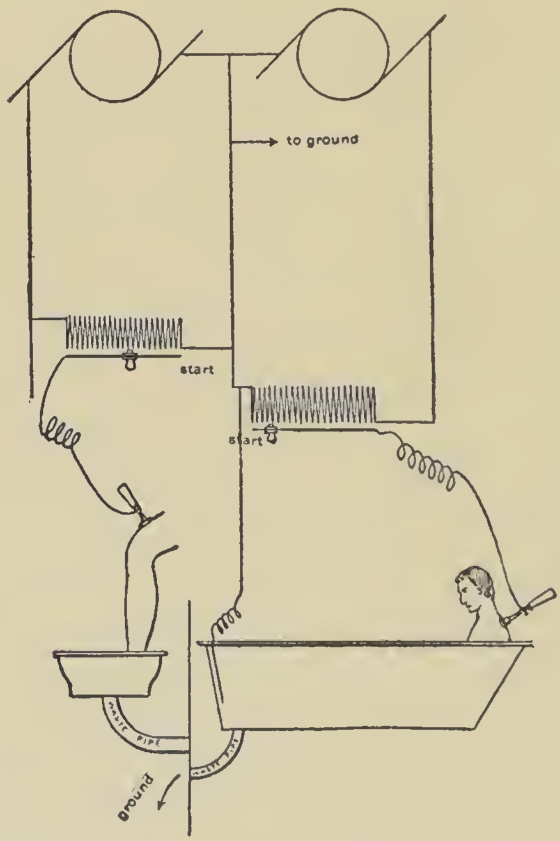

FIG. 136.—DIAGRAM SHOWING WHERE THE CONTROLLING APPARATUS SHOULD BE PLACED IN ORDER TO AVOID DANGER.

transformer. As a consequence, the secondary windings would have their potential very materially raised. This is an occurrence that cannot be guarded against, so the only remedy lies in some arrangement by which the current would be cut off in that event.

Various apparatus for this purpose exist: In one the secondary mains are automatically connected with the earth upon a dangerous rise in potential; in another a second transformer is in circuit with

the patient; or, finally, we may make use of a magnetic cut-out in the circuit, so that upon rise in the pressure of the current the cut-out will gradually diminish the current to zero. Fusible cut-outs and lamps as safeguards are worse than useless, for they induce us to place confidence in apparatus that will never act promptly, as they require time to melt or to break. But even the safety cut-outs first spoken of, no matter how well constructed, must fail to guard the patient against a momentary shock

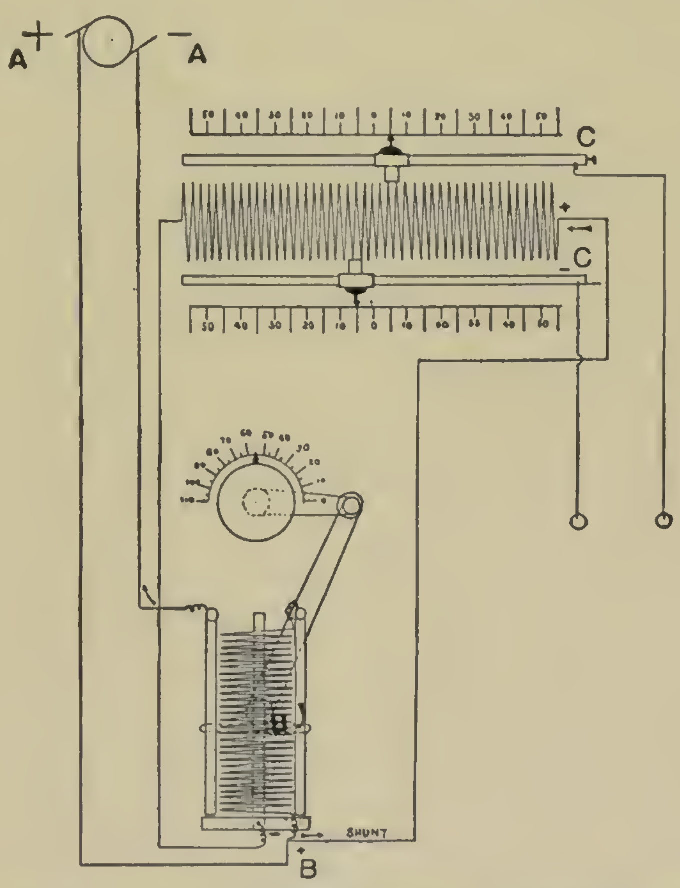

FIG. 137.—DIAGRAM SHOWING HOW THE CURRENT IS DERIVED FROM A DOUBLE SHUNT CIRCUIT.

that, no matter how short in duration, may, for all that we know to the contrary, do irreparable damage.

No safety cut-out can act before the increased current has reached it, and so soon as the current has done this, it has also passed over to the other end of the line.

As previously mentioned, another source of danger may lie in a sudden increase of current on the line in consequence of an

accident at the central station, or through the crossing of the supply wires by wires from another source—*e. g.*, arc lights. While this is not likely to happen in New York city, a method should be provided to guard against possible danger from such an occurrence.

This danger may practically be overcome by the employment of a **compound shunt.** Here the shunted current is again shunted, and the already reduced voltage again reduced. No more delicate graduation of a current can be imagined than the one obtainable by this means. A reference to figure 137 will make this clear.

The current is first regulated by the resistance controller at B. If the full resistance be interposed, all the current will pass through the shunt, and the quantity of current in the shunt circuit is proportional to the interposed resistance. Now, following the shunt circuit to C, the process is repeated by shunting the current again and placing another resistance controller in one arm of the shunt, so that the ultimate current is the result of a double shunt. I believe that this is the first time that this idea has been practically applied.

How to Use the Central Station Currents.—We are now in a position to use any current at our disposal for any purpose that may be desired.

It is simply a question of a suitable device for controlling the current for the purpose in question, and of placing this device at the proper location in the circuit.

The device for controlling the **direct current** from the main will differ from that necessary to control the battery current only in its adaptation to the larger volume of current that we make use of. The principles governing such adaptations are as follow:

1. In galvanization of the human body no more than one ampère of current is needed; therefore additional resistance sufficient to limit the volume to this amount should be placed and allowed to remain **in series** with the controlling device. This is the limit resistance and is nonvariable. As such a limit resistance, incandescent lamps have been used, the lamps limiting the current in accordance with their candle-power; thus, with a 110 volt current an 8 candle-power lamp would limit the current to ¼ of an ampère; a 16 candle-power lamp would limit the current to ½ of an

ampère; a 32 candle-power lamp would limit the current to 1 ampère; a 50 candle-power lamp would limit the current to 1½ ampères; but these limits are only correct when these lamps are at full incandescence, as the carbon filaments have a great deal higher resistance when below incandescence. On the other hand, the life of the lamp is limited and the filament is apt to break, or may become detached from its socket, even before it is exhausted, by a sudden jar, and thus the supply of current may suddenly be cut off.

A wire resistance of the necessary capacity has very many advantages: it furnishes a trustworthy and invariable resistance; it will not deteriorate, and, if properly arranged, it will not get out of order.

2. We must, further, make use of some contrivance for regulating the intensity and the quantity of the current thus obtained.

In all contrivances now in use, together with a galvanic controller (rheostat), lamps are employed for shunting off current—that is, for reducing the voltage or intensity. Nothing can be more reprehensible than an arrangement of this kind, for should such a shunt lamp break down or loosen from its socket, the voltage passing through the patient would suddenly and very materially be augmented.

For affecting the relative intensity of a current a rheostat of considerably higher resistance is connected in series with the limit resistance, and from this rheostat we derive our current, properly modified and perfectly adjustable.

In the construction of rheostats for use with the street current we must not fail to consider that a greater quantity of heat is apt to be generated in the resistance cylinders than would be the case if the battery current were used.

This heat-production must, if possible, be guarded against, not only because it may be so great as to fuse the wires, and thus destroy the apparatus, but also because the resistance in the controlling device will vary with the temperature and thus interfere with accurate measurements. This is the main reason why carbon rheostats are more or less unsatisfactory when used in connection with the street current.

The only satisfactory rheostat for use in connection with the street current is a metal resistance device of proper capacity, with sufficient heat-radiating surface.[1]

The method that I employ for the regulation of the current (voltage and ampèrage) from the main is, therefore, as follows:

A limit resistance made in accordance with the foregoing principles is inserted at the point of entrance.

A resistance cylinder is placed in the main circuit, from which the current is shunted.

This **shunt current** is passed through another controller, and herefrom is derived another current; and in this circuit the patient is placed.

The current in the shunt circuit will always be dependent upon the proportionate resistances of the main circuit and of the shunt circuit; the current following the path of least resistance. In the resistance apparatus in the main circuit (first volt controller) two terminals or slide contacts are employed, for the purpose of varying the relative resistances according to their position upon the cylinder. If the terminals are at opposite ends of the resistance cylinder, the entire resistance is interposed in the main circuit, and the maximum amount of current obtainable will flow through the shunt circuit. As the contacts are approached to each other, the interposed resistance in the main circuit grows less and the current in the shunt circuit becomes correspondingly diminished, until they

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[1] Heating capacity: 110 volts will send ½ an ampère through 220 ohms; if this resistance be made to consist of a thin wire about four feet in length, it would at once become red-hot when connected with a 110 volt circuit; if the wire were made longer, it would necessarily have to be made thicker in order to keep its resistance at 220 ohms; then, while the same quantity of heat would actually be generated in the wire, it would, nevertheless, not become so hot as in the case of the thinner wire, because it presents a larger surface to the surrounding atmosphere, and thus permits of the escape of more heat. Therefore the greater the heat-radiating surface, the less heat will be generated throughout the entire resistance. If, however, we take the thicker wire, and, instead of connecting it to a 110 volt circuit connect it to one of 220 volts, we should again have the same state of affairs. It is thus apparent that our resistance must, in addition to having ample heat-radiating surface, also be adjusted in accordance with the pressure of the available source, and the resistance body selected must be of sufficient capacity to carry the limit of current required for the special purpose.

are directly opposite to each other on the cylinder, when no current will flow in the shunt. The electromotive force of the shunt current will also depend on the resistance in the main circuit, as already elucidated.

Owing to the construction of the resistance cylinder, the variations in the intensity of the shunt current take place very gradually by small fractions of a volt.

The shunt current then selected is still further reduced by the second controller, which is constructed similarly to controller No. 1, only that it is so modified that no switch is required to turn the current on and off. The same movement (hand or motor power) that actuates the slide contacts turns the current on and off by means of two bars and a spring that traverses them. These circuit-breaking bars run parallel with one of the slide bars, and each one forms a continuous conductor from one end of the resistance cylinder to the other; but at that point at which the two slide contacts are directly opposite to each other, the spring, which has formed an electric connection between the two bars, is forced to ride into an insulation, thus breaking the electric contact between the two circuit-breaking bars; then no current will pass through the controller.

The current in the shunt cannot be shut off without gradually diminishing it to zero.

CHAPTER IV

APPARATUS FOR ALTERING ELECTROMOTIVE FORCE

Induced or Faradaic Currents. Magneto-electric Machines. Volta-magnetic Machines. Dubois-Reymond Coils. Faradimeter. Standard Coils. Current Source. Sinusoidal Currents and Apparatus. Apparatus for High Frequency Currents. Hydro-electric Baths. Cautery Apparatus. Transformer. Commutator. Storage Cells. Exploring Lamps.

Mechanical Induction Apparatus.

The first **induction machines** used in medicine were magneto-electric or rotary apparatus. These machines were used for a long time, but were finally entirely displaced by the volta- or electro-magnetic apparatus. Without going into the history of these machines or describing them in detail, an illustration may

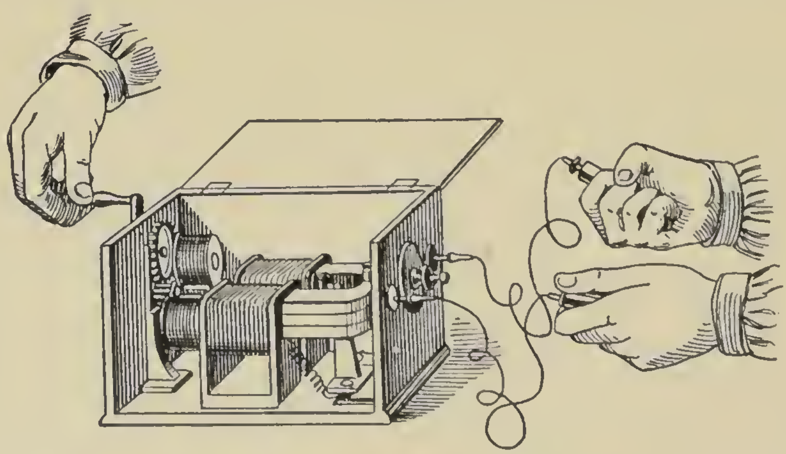

FIG. 138.—MAGNETO-ELECTRIC MACHINE.

be given, so that the student shall not be entirely unfamiliar with their appearance. (See Fig. 138.)

The advantages of such machines are that they always, without special preparation, furnish a current that, with equable rotation, possesses one and the same intensity; they are durable; the cost

of maintenance is reduced to a minimum, and they may be used for the production of unidirectional or of alternating currents.

In order, however, to accomplish all this, the machine must be complicated in its construction, and must be made so large that its portability is sacrificed. Furthermore, an assistant is necessary to rotate the coils or magnet, and the regularity of such rotation leaves much to be desired. With irregularity of rotation current fluctuations are unavoidable. The use of a motor for purposes of rotation is complicated and impracticable. For these reasons and because the volta-induction apparatus works automatically, admits of modification of the current intensity and of the current interruptions, is perfectly portable, and is very much cheaper, it has, for all practical medical use, displaced the old magneto-electric machines.

Volta-induction Apparatus.

The volta-induction apparatus manufactured for medical purposes vary considerably in shape and appearance, but the principles of construction remain the same. These principles are :

1. The **primary coil**, the function of which is to furnish a path for the battery current and to interrupt and transform that current in such a manner as to create induced currents in a secondary coil near by, need be made of but few turns of comparatively coarse wire. For the purpose of giving a different quality to the primary current the number of turns may be increased. This primary coil surrounds

2. The **temporary magnet**, which consists of a soft-iron bar or a bundle of soft-iron wires, and becomes magnetized when the battery current flows through the primary coil, again losing its magnetism when this current is interrupted. This magnet, in addition to augmenting the inductive action, may also be made use of to interrupt the current automatically through the aid of

3. **The Circuit Breaker or Interrupter.**—The current that flows through the primary coil around the wire core must be broken at intervals in order to effect the change of electromotive force necessary to the creation of induced currents. Such interruptions are produced in the ordinary coils by means of a spring, one end of which is fastened to the base of the apparatus, the other

end being free directly on a line with the wire core, and having an iron head attached to it. The tension of the spring is regulated by means of a set-screw. This interrupter, with its connections, is shown in figure 139.

The current passing through the primary coil, P, magnetizes the

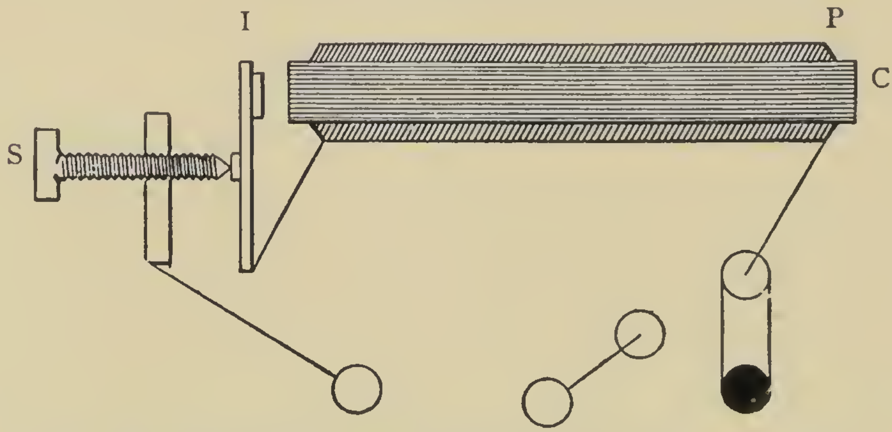

FIG. 139.—SHOWING CIRCUIT BREAKER AND ITS CONNECTIONS.

iron core, C; by its magnetic force it attracts the head on the interrupter, I, and draws the spring away from the adjusting screw, S, thus interrupting the current. As soon as the current is interrupted the iron core loses its magnetism and releases the spring,

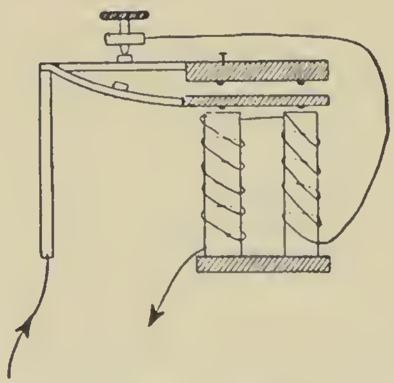

FIG. 140.—THE NEEF OR WAGNER HAMMER.

which flies back and again comes in contact with the set-screw, thus recompleting the circuit.

In many induction coils the interruptions are effected by means of a Neef or Wagner hammer (Fig. 140). Here a special electromagnet is employed.

When the spring in either form is in action, small sparks will be seen to pass between the spring and the adjusting screw. Hereby small particles of metal are torn off from both plate and screw point, which in time become markedly worn. In order to prevent this wear and tear as much as possible the screw point and plate are made of platinum. Hereby, also, the oxidation of these parts is, to a certain extent, prevented. The rapidity with which the current can be interrupted by means of this mechanism varies greatly in different instances, depending upon the length of the spring, its elasticity, etc. ; each such spring can, however, be regulated within certain limits, so that the interruptions become slower or more rapid. The sooner the spring meets the screw point again after having been drawn away from it by the electromagnet, the more rapid will be the vibrations ; therefore the further we screw the point down, without, however, screwing it so tightly that the spring is prevented from vibrating, the more interruptions will we have ; and the further the point is screwed back, yet allowing the spring to make good contact, the fewer interruptions will we obtain. The interruptions may be varied still more, as regards their relative slowness, by lengthening the spring, through the attachment of a rod upon which a metal ball can be raised and lowered, or by means of a rod and ring, as in Flemming's apparatus. For special work the interruptions may be effected by means of clockwork, or Engelmann's segmentary rotary interrupter, run by an electric motor, may be employed. Thus great variations and regularity of interruptions are obtained ; but for all practical purposes the simple Wagner hammer will answer.

4. The **secondary coil**, or the induction coil proper, must be made of finer wire than is used for the primary coil, have a greater number of windings, and the length of wire be proportionately increased. The increased length of wire necessitates an increased number of turns in each layer. The lines of magnetic force emanating from the primary coil and temporary magnet are increased proportionately to each extra turn, and are cut by the secondary coil. In consequence of this a greater number of windings is deemed advantageous by some. But this advantage, derived from the increased length and num-

ber of turns of wire of the secondary coil, has its limit. The primary battery may not be able to overcome the increased resistance, and, in addition, a self-induction current is set up, thus materially reducing the secondary induced current. The efficiency of the faradaic apparatus depends greatly on the nature of the current derived from the secondary coil, and at times different forms of current are required for various therapeutic purposes. To meet this need the manufacturers of apparatus have arranged various devices. Some furnish a series of coils wound with graduated turns and thicknesses of wire. Others use a very long wire, of uniform thickness, with many turns, and tap the wire at regular intervals by means of a switch; thus required portions or even the whole coil can be thrown in.

This secondary coil may be fixed, or may be movable along a

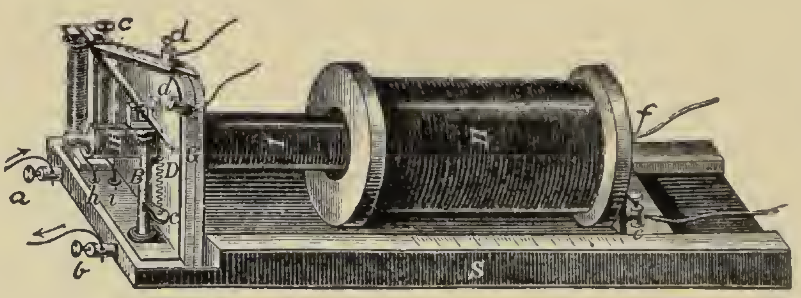

FIG. 141.—DUBOIS-REYMOND COIL.

track, sliding over and covering or uncovering the primary coil to any desired extent. If the coil slides, the track along which the secondary coil moves should be graduated with a millimeter scale, in order to show the extent of primary coil and core that at each move of the secondary coil still remains covered by it. Such an apparatus is shown in figure 141, and is known as a Dubois-Reymond coil. Upon the horizontal base *S*, which forms the track for the secondary coil, is fastened the horizontal millimeter scale and the vertical head-board *G*, which carries the primary coil *I*, the binding posts *c d* for the extra current, as well as supporters for the interrupter. Upon the track itself is mounted a secondary coil, *II*, which is movable over the primary coil; the latter having in its interior the iron core, *III*, made up of bundles of wire.

In addition hereto we see upon the head-end two binding posts,

a, *b*, for the battery connection, and at the foot of the secondary coil two binding posts, *e*, *f*, for the secondary current. If the poles of the current source are respectively connected with *a* and *b*, the current flows first through the automatic interrupter, which is thereby set into action, and then through the wires of the primary coil. The extra current may be obtained by connecting the electrodes with *c* and *d*, while the secondary current is obtained by connecting them with *e* and *f*.

The **strength of a current** from an induction apparatus may be controlled in a variety of ways, by regulating the strength of either the primary or the secondary current. In the forms of apparatus in which the secondary coil is fixed, the strength of the current is regulated by means of a movable iron core or by means of a damper. In the first case the core of soft-iron wires around which the primary coil flows may be pulled out or pushed in. The primary current is weakest if the core is drawn out, and becomes proportionately stronger the further the core is pushed in. In the second case the electromotive force is altered by sliding a brass or copper tube over the fixed wire core, thus cutting off the inducing effect of the core entirely when it is completely covered, and increasing it as the damper is drawn out—*i. e.*, the core uncovered.

In the apparatus of the Dubois-Reymond type the current strength is regulated by varying the extent to which the secondary coil covers the primary one, in the manner already described. For all diagnostic purposes this method of current regulation is the one that should be chosen.

Measurement of Induction Coil Currents.

The arguments advanced in support of the use of instruments of precision in the employment of the voltaic current for medical purposes apply with equal force to the induced currents. While the quantity of any direct or uninterrupted current flowing at a given time can be measured satisfactorily by means of a galvanometer introduced into the circuit, no instrument has as yet been devised that is capable of doing this for induction coil currents. The induced current that arises in the primary coil being a current of

one direction, may, by means of a very delicate galvanometer, be measured approximately, but the current flow is, on account of the interruptions, of so short duration that the needle cannot come to rest, and no actual reading of the galvanometer scale can therefore be made. The secondary current is alternating as well as interrupted, and no alternating meter exists that will register the small currents of the secondary coil.

As the chief effects of an induced current depend upon the quantity and electromotive force of the current, we must demand of any serviceable meter that it record either the quantity of current in the circuit or the voltage of the current. This is being done in a crude and unsatisfactory manner by the millimeter scale, which indicates the relative position of the coils. Inasmuch as the strength of the induced current depends upon the strength of the inducing current, upon the number of turns and size of the wire used in the coils, and upon the size and shape of the temporary magnet, it will readily be seen that any scale can serve only as an approximate index to the strength of current in the individual apparatus for which it is constituted, and even then must entirely disregard the variations of the strength of the primary and secondary currents, due to variations in the strength of the current from the exciting source.

Von Ziemssen and Edelmann have attempted to correct the fault due to variations in the inducing current by introducing an *adjustable resistance* in circuit with the primary coil, thus affording a means by which the resistance in the primary coil may be altered in accordance with the variations in strength of the current from the primary source, and the strength of the inducing current be kept constant.

In the Edelmann *faradimeter*, as this instrument is called, the inducing current is kept constant at 300 *milliampères*.

With the inducing current constant, the inducing effect upon the magnet and secondary winding will correspondingly be constant. The scale that accompanies the instrument is graduated in *volts*, from 5 to 200, and so long as the strength of the inducting current is exactly 300 milliampères, the number of *volts* marked on this scale, along which the secondary coil slides, is correct. In theory this instrument is perfectly trustworthy so long as there is a fixed

resistance between the terminals of the secondary coil; but in practice this resistance, whether in diagnostic or therapeutic applications, is constantly varying, so that the actual voltage in the circuit will rarely correspond with the figures indicated upon the scale.

Even admitting that the method is practical for scientific use, it requires not only a specially constructed induction coil, but also special measuring apparatus; these facts will act as an obstacle to its general use for therapeutic purposes. Nevertheless, some system of uniformity in the construction of coils should be observed; for at present, on account of the varied dimensions given to coils by different makers, even with the specification of the kind of cell employed as well as the distance between the primary and secondary coils, the current from one apparatus cannot be compared with that furnished by another. Thus the results obtained diagnostically or therapeutically by one observer cannot be tested accurately by others. At the general meeting of the International Electrical Congress, held in Paris on September 28, 1881, it was resolved that the simple statement of the distance between the primary and secondary coils of a Dubois-Reymond sled apparatus suffices for the determination of the induced currents used in electrotherapy, provided that in its construction an apparatus of standard dimensions be used as a model, and that one and the same kind of cell be used as current source. The normal apparatus recommended possesses the following dimensions:

	Primary Coil.	*Secondary Coil.*
Length of coil,	88 mm.	65 mm.
Diameter of coil,	36 "	68 "
Diameter of wire,	1 "	0.25 "
Number of turns of wire,	300	5000
Number of layers of wire,	44	28
Resistance, about	1.5 ohm	300 ohms.

The **current** for working an induction apparatus must, if cells be used, be obtained from cells having a low internal resistance and as high an electromotive force as possible. The best cell for this purpose would be the Grenet, but on account of the trouble attendant upon frequent recharging and the necessity of immersing and removing the zinc each time before and after using the apparatus, other cells are practically more convenient.

For nonportable apparatus, those that form part of the stationary office outfit, large Leclanché cells are most desirable. **For portable induction coils** a dry Leclanché cell will be found eminently satisfactory. **For experimental purposes** the greatest constancy of the inducing current can be obtained by the use of thermopiles. They are started by lighting a small gas, oil, or spirit flame. Their convenience, reliability, and durability leaves little to be desired. The direct current from the central station may likewise be used, and will be found unobjectionable.

In order not to burn the platinum contact plate on the interrupter of the ordinary faradaic coil, it is necessary to reduce the pressure of the direct current to that which would be obtained from two or three cells—*i. e.*, four volts.

A rheostat, as already described, may be used for this purpose, but it is unnecessary to limit to 1½ ampère, or to go so high as twenty-three volts. In fact, all that would be required for operating the coil would be a lamp of thirty-two candle-power in series with a four to six ohm resistance wire of one ampère capacity. This would make it equal to a three or four cell battery, because a shunt or parallel connection with six ohms carrying one ampère yields about six volts at one ampère—*i. e.*, $\frac{110 \times 6}{110 + 6}$, or 5.6. volts. If desirable, this could be still further regulated.

Sinusoidal Apparatus.

It is not at all easy to construct a machine that will generate a true sinusoidal current, on account of the difficulty of producing a magnetic field that will not vary while an armature containing iron is revolved in it. As previously stated, the magneto-electric machine generates a current approximately sinusoidal in character.

Dr. J. H. Kellogg, of Battle Creek, Mich., has for a number of years used a common magneto-generator, wound for about fifty volts at 3000 revolutions, as a source of sinusoidal currents. A magneto-generator can be made to give a current that is more nearly sinusoidal than is that obtained from the ordinary machine, by properly shaping the pole pieces and armature. In his machine (Fig. 142) Dr. Kellogg has not only done this, but has replaced the permanent magnet by a separately excited electromagnet, thus

permitting of a variation of the electromotive force generated without varying the speed of the armature.

Mr. A. E. Kennelly has designed an alternator for electrotherapeutic purposes, shown in figure 143, in which the principle of

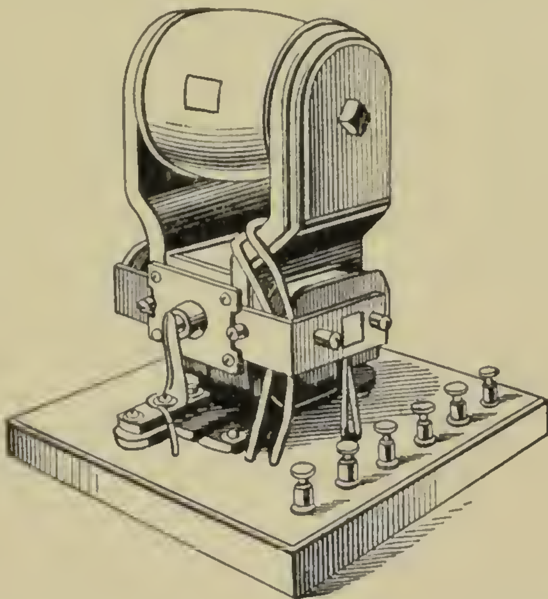

FIG. 142.—MAGNETO-GENERATOR FOR DEVELOPING A SINUSOIDAL CURRENT.

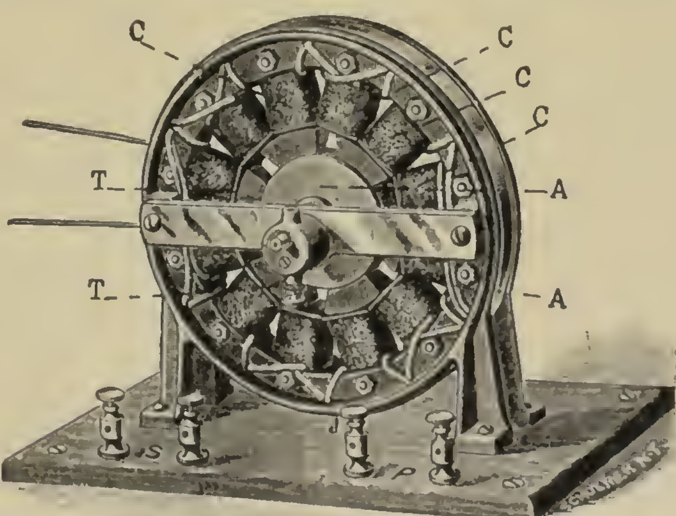

FIG. 143.—AN ALTERNATOR FOR GENERATING A CURRENT OF THE SINUSOIDAL TYPE.

magneto-electric induction is applied in a different manner. This machine, which in my experience is the most satisfactory small alternator obtainable, consists of 12 coils, C, C, C, C, on the field frame, wound with two circuits, one of coarse wire, excited by a

continuous current from a pair of binding posts, P, and a fine wire circuit connecting with the binding posts S. The armature A, A, which is rotated by a small pulley at one end of the shaft, is constructed of sheets of soft iron and carries teeth, T, T, in such a manner as alternately to open and close the magnetic circuits of the coils C, C, C, C. Each revolution of the armature produces twelve complete periods, or twenty-four alternations. As soon as the teeth bridge across adjacent poles, magnetic flux is poured through the secondary or fine wire circuits, inducing in them an electromotive force in one direction, and as soon as the teeth pass beyond this position, the magnetic circuits are open and the secondary coils emptied of flux, thus inducing an oppositely directed electromotive force.

This alternator furnishes an alternating current of approximately sinusoidal type, whose alternations are, within certain limits, under control, according to the speed with which it is driven. The electromotive force obtainable from such a machine is about fifty volts.

The electromotive force of the secondary circuit depends upon the strength of the inducing or primary current, and this may be varied, independently of the frequency, by means of a rheostat placed in this primary circuit. This circuit may be derived from primary batteries or from central stations, and should have a capacity of two ampères.

Apparatus for High Frequency Currents.

The simplest arrangement for obtaining alternating currents of high frequency for medical purposes is that described by d'Arsonval. He makes use of a *condenser* connected with a powerful *induction coil* (a Ruhmkorff coil), capable of giving a spark of from 15 to 25 centimeters, and conducts the current from such a coil into the inner armatures of two Leyden jars. The external armatures of these jars are connected by means of a solenoid of thick wire. (See Fig. 144.)

When the ends of the conductors attached to the internal armatures of the jars are approached near to each other, a discharge of sparks takes place, and the solenoid is traversed by an alternating current of high frequency, which may be utilized by the attachment

of conductors to this solenoid; the current thus obtained will be increased proportionally as the number of turns of the solenoid comprised between these conductors is increased. If it is desirable still further to augment the electromotive force, the solenoid of thick wire may be made to act upon another solenoid of fine wire.

The Ruhmkorff coils are usually so constructed as to be worked by a current from a primary or a secondary battery; if the 110 volt electric-light current is to be used for this purpose, special modifications of the coil become necessary. The solenoid may be of

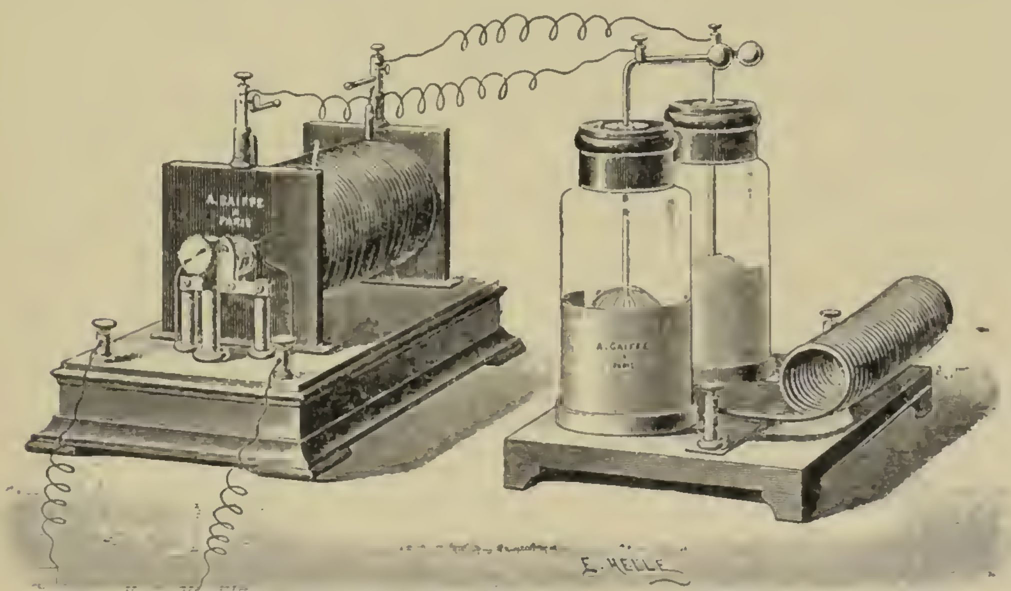

FIG. 144.—APPARATUS FOR OBTAINING A HIGH FREQUENCY CURRENT.

various sizes—even so large that the entire body of the patient may be incased by it.

These high frequency currents, caused by the oscillations of a charge in a solenoid, may be made to act upon a subject in three different ways:

1. **By shunting the current** through the body of the patient. The patient is connected in a shunt circuit with any two points of the solenoid, and the current is applied to the body by means of electrodes similar to those used in galvanization and faradization.

2. **By autoconduction.**—The patient or the part to be acted upon is placed inside of the solenoid, without having any direct connection with any part of the circuit.

3. **By condensation.**—The patient, connected to one point of the solenoid, forms an armature of a condenser, the second armature being connected at another point or being made up of the remainder of the solenoid (unipolar application).

Apparatus for Hydro-electric Baths.

Galvanic and faradaic currents may also be conducted to the human body by means of a *bath*. The patient is immersed in water, to a greater or less extent, and the water, which is in direct contact with the body, constitutes the electrode by which the current is applied. Two methods of arranging such baths must be differentiated, the **monopolar** and the **dipolar.**

In a **monopolar bath** the wall of the metal tub is utilized as a large electrode. The current entering here is conducted to the entire surface of the body that is in contact with the water, and passes out by means of an iron bar covered with wet chamois skin, which is grasped in the hands. The metal tub should have a perforated wooden lining, so that the body of the patient will not directly touch the metal. Better still would be the use of a wooden tub, with a large plate electrode entering it. There is, however, one objection attached to this form of bath, no matter of what material the tub is made—namely, that the grasping of the metal bar concentrates so much of the current upon the hands that a severe contraction of all the muscles of the hands and arms takes place, while the current that is spread over the remainder of the body is hardly perceived. The metal bar, therefore, should be discarded, and in its stead a large metal electrode of about 400 square centimeters surface, whose edges are covered by a rubber pillow filled with water, should be so placed in the bath that the patient can lie upon it without coming in contact with the metal.

Eulenburg, in the use of the galvanic current water-bath, differentiates the **kathodal** and **anodal** baths: in the former the water constitutes the negative, in the latter the positive, pole.

In the **dipolar bath** the body of the patient does not come in contact with either of the electrodes, but these are immersed in the water, one at each end of the tub. The number of such electrodes may be increased, and in such case they are so placed in the

sides of the tub that they are covered by the water but cannot come directly in contact with the patient.

The source of **current supply** may be either a battery or a central station; if a battery, it may be placed at any distance from the tub. The apparatus for current control should be placed in the bath-room itself, and should be the same as other

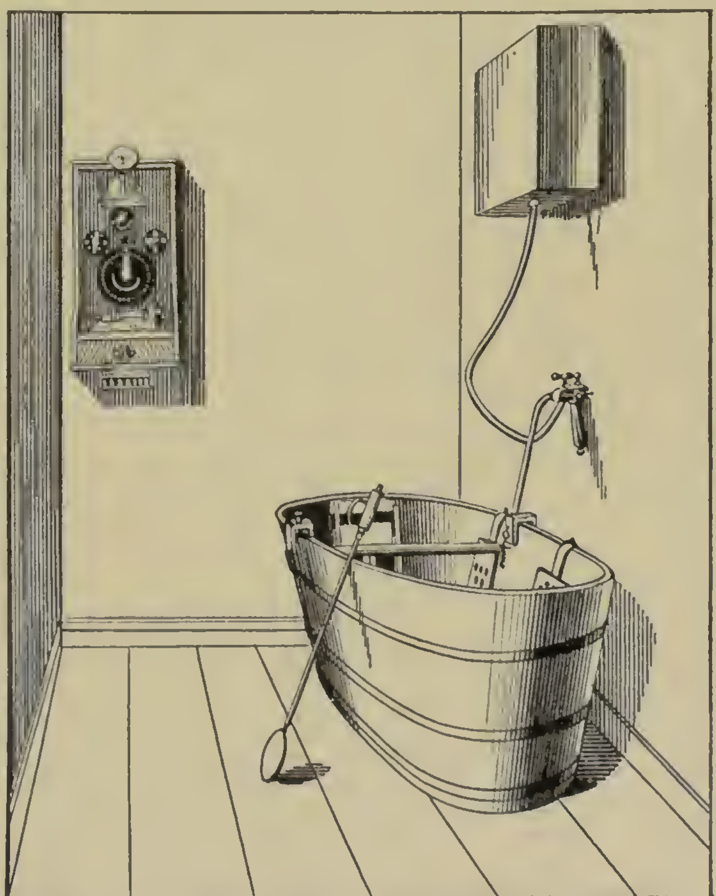

Fig. 145.—Simple Form of Electric Bath-tub.

controllers used for current application. Such an electric bath-tub of very simple form, as made by Hirschmann, is shown, with its various accessories, in figure 145.

Cautery.

The heating effect of the electric current may be utilized directly for the purpose of raising the temperatures of suitably shaped platinum wires to a red or white heat; the wires so heated are used

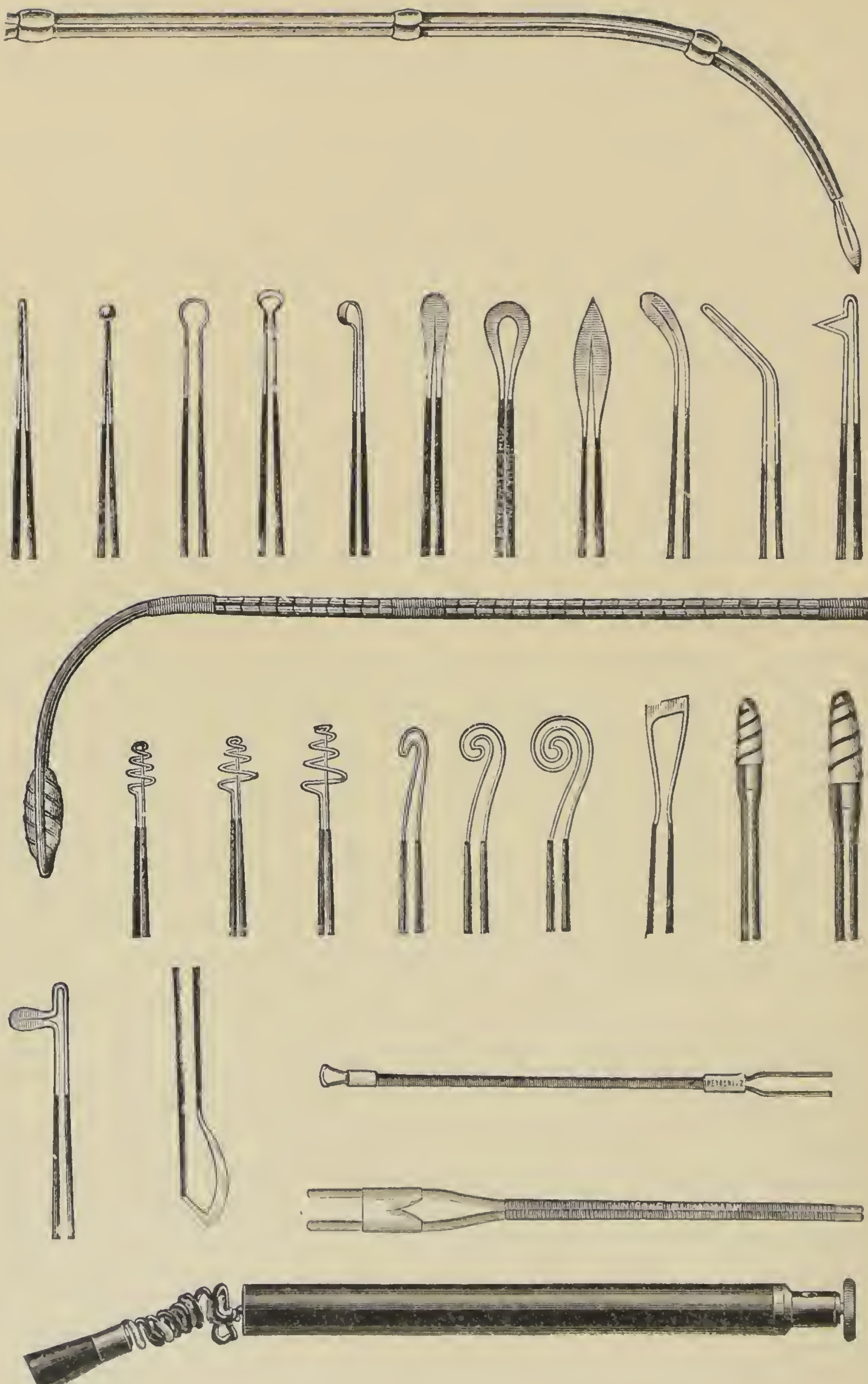

FIG. 146.—HANDLE AND VARIOUS ELECTRIC CAUTERY ENDS.

for cauterizing purposes. Electric cautery ends of various shapes are shown in figure 146.

A very strong current is required for thus heating platinum wires of the thickness needed for cautery operations, for most of the burners require from fifteen to twenty ampères, and in order to keep a current of this strength constant, even for a few minutes, large cells are necessary. The resistance of the external circuit, however, being very low, a small number of cells of a low internal resistance will suffice for the production of such a current. We must not, however, forget that the quantity of current necessary for the heating of a cautery knife depends also upon the radiating surface that it possesses, so that a broad flat knife requires more current than a narrow one.

The majority of cells are not suitable for cautery purposes, on account of their high internal resistance. The Bunsen and Grove cells are too troublesome to be of practical use. The best cells for cautery purposes are undoubtedly the bichromate. The chief objection to their use is their inconstancy, but if they are made of ample size, they will be sufficiently constant for all cautery operations.

It must, however, be clear that a current sufficiently powerful to be used for cautery purposes can be more easily obtained from a central station line than from batteries. Various devices have accordingly been constructed for the purpose of utilizing directly the current from the main. Among the first of these was a rheostat of twenty ampères capacity. Here, however, in order to have the use of a comparatively small quantity of energy, an enormous quantity is wasted, and an intense heat is generated in the rheostat in a very short time. This appliance proved very inconvenient, because a shunt current of an intensity of about ten volts only had to be obtained in order to avoid the heating of the contact and of the cautery handle. The use of a motor dynamo seems to offer a better source of current for cautery work. This apparatus may be called a rotary transformer, and consists of a machine of one common field and two windings on one armature, each winding having its proper commutator. The 110 volt current used as a motive power is passed through a fine wire, and is

returned in a transformed state, fit to heat cautery electrodes and snares. Or the 110 volt direct current may be utilized for cautery purposes by placing collector rings upon the armature shaft, and connecting them to opposite segments of the commutator; from these collecting rings an alternating current is obtained that is nearly of the same intensity as the current from the main, but is easily transformed by means of a proper step-down transformer.

It is, however, my conviction that these outfits as to-day placed upon the market are mere toys. For efficient work a motor of less than one-quarter horse-power is entirely out of the question. I believe that a good storage battery is more reliable and more economical for cautery work than any of the preceding appliances.

Storage cells, called also accumulators or secondary cells, are made in a number of forms. The principle of their formation is the following: If two lead plates or lead grids containing lead oxid are immersed in dilute sulphuric acid, and through such a cell a constant current is passed, oxygen will, through electrolytic decomposition of the water, collect at the plate through which the current enters, and will combine with PbO to form PbO_2; upon the other plate hydrogen collects and reduces the lead oxid to metallic lead, which, in a finely divided form, constitutes the so-called porous lead, or lead sponge. When all the lead oxid has thus been transformed, the storage cell is charged to its full capacity. If, now, this cell be disconnected from the charging source and the free ends of the two lead plates be connected by a conductor, a current will flow through this conductor in a direction opposed to that of the charging current. This current flow will continue until both lead plates have returned to their original conditions. The cell is then discharged, and must be recharged for further use.

Storage cells are now manufactured so that they may easily be transported, and will give perfect satisfaction if used constantly. When a battery is to be used for occasional work, a storage battery should not be selected. Storage batteries are best charged from a direct line. In order to prevent too great a flow of current, resistance must be inserted into the circuit in the shape either of incandescent lamps or iron wire coils. The positive wire of the line must be connected with the positive pole of the battery, the negative

wire of the line, with the negative pole of the battery. Full directions as to time of charging, care of cells, etc., accompany all purchasable batteries.

Exploring Lamps.

A thin platinum wire or a fine carbon filament connected in the circuits of several cells of high electromotive force and low internal resistance will be heated to an incandescent state. Such uncovered incandescent platinum spirals have been made use of in connection with small metallic reflectors, for the purpose of direct illumination

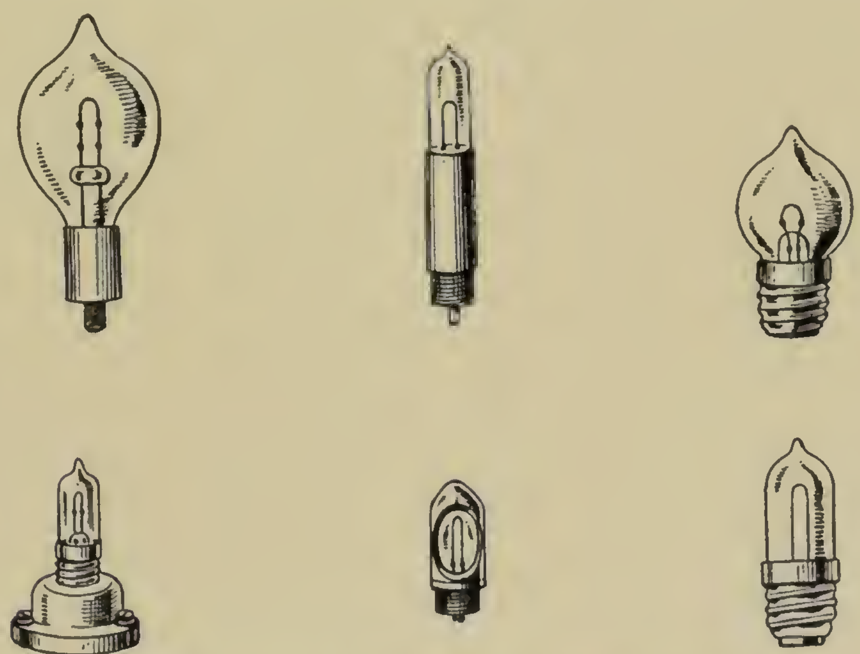

FIG. 147.—SET OF MINIATURE EXPLORING LAMPS.

and visual examinations of the accessible body-cavities. On account, however, of the heat produced and of the danger of burning the tissues, they presented fewer advantages than reflected daylight or lamplight. Since the discovery of the Edison filament of carbonized vegetable fiber small incandescent lamps entirely inclosed in an airtight glass chamber have been constructed, whose introduction into the body-cavities is not only feasible, but entirely unobjectionable. A set of such miniature lamps is shown in figure 147. Such exploring lamps require a current pressure of from four to fifteen volts, and a current strength of from $\frac{1}{4}$ to $1\frac{1}{2}$ ampère.

Care must be exercised in the employment of such lamps that the pressure shall not exceed that for which they are designed. They may be operated by a battery or by a current from the main line. Under all circumstances a controller should be used. If the main current of 110 volts be employed, a 50 candle-power lamp, allowing 1½ ampère of current to pass, and a volt controller in series with the exploring lamp, should form the circuit. The controller having a capacity of 1½ ampère need not have a resistance

FIG. 148.—LAMP FOR USING REFLECTED LIGHT.

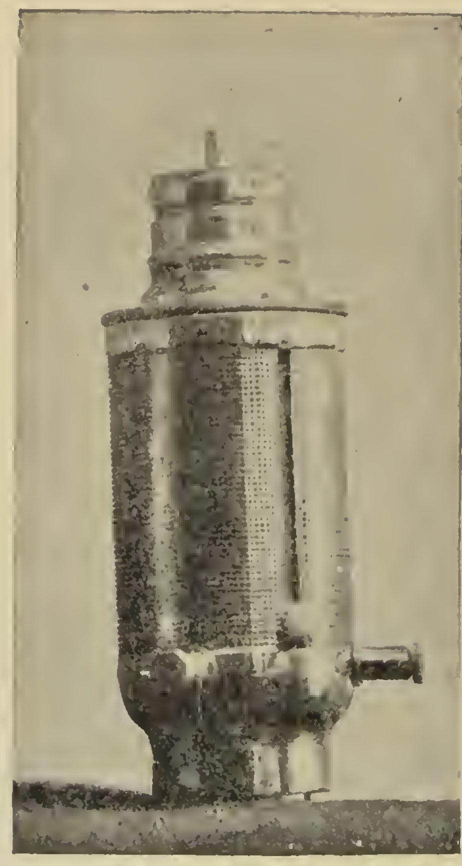

FIG. 149.—THE WAPPLER ELECTRIC CONTROLLER.

of more than 20 ohms. For the use of reflected light the ordinary filament is inadmissible, as the reflection of the filament in the mirror interferes with the examination. E. B. Meyrowitz, of New York, furnishes a lamp in which this objection is overcome through a spiral arrangement of the filament. (See Fig. 148.)

An excellent controller, made in accordance with the principles already enumerated for the regulation of the line current, and adapt-

ing it for the operations of small lamps, faradaic coils, small motors, etc., is made by the Wappler Electric Controller Company, of New York, and is shown in figure 149. This apparatus is devised to carry the current for a 110 volt 16 candle-power incandescent lamp. In the derived current from the two binding posts a current of 80 volts and 1 ½ ampère can be obtained, and while the voltage can be reduced by steps of ⅓ of a volt to zero, the ampèrage will remain the same. As a light-regulating device, not only for exploring lamps, but also for use in hospital wards, sick-rooms, or wherever it becomes necessary to lower a light without completely extinguishing it, its action is unsurpassed.

CHAPTER V

RÖNTGEN RAYS OR X-RAYS

Production of X-rays. Characteristics. Properties. Source. Geissler Tube. Crookes Tube. Kathode Rays. Antikathode. Focus Tubes. Adjustable Vacuum Tubes. Excitation by Influence Machine. Excitation by Ruhmkorff Coil. Condenser. Interrupter. Fluoroscope. Skiagraphy. Radiographic Table. Localization Methods. X-Ray Burns.

Apparatus for the Production of Skiagrams and for the Transillumination of the Body by Means of the Röntgen Rays.

The importance that the Röntgen rays have attained in surgical and medical diagnosis for purposes of skiagraphy and for transillumination of the deep tissues and organs since December, 1895, when Professor Röntgen, of Würzburg, announced his discovery, is so great and their promise of greater usefulness is so far-reaching that a description of the basic principles and necessary apparatus seems to be indispensable in a treatise like the present.

Without entering upon the diagnostic certainties and the therapeutic possibilities that this newly discovered form of radiation offers, let us first consider what these Röntgen rays are.

Röntgen discovered that glass tubes in which a very high vacuum existed were capable, under electric excitation, of emitting a radiation for which he proposed the name of **X-rays**, or "the unknown rays." No better description of the peculiarities that the Röntgen rays possess can be given, than that of Röntgen himself. He says:

"When a discharge from a large induction coil is passed through a Hittorf vacuum tube or through a well-exhausted Crookes or Lenard tube, it is possible to see, in a completely darkened room, that paper covered with barium platinocyanid lights up with brilliant fluorescence when held toward the tube. Calcium sul-

phid, uranium glass, Iceland spar, rock-salt, and other bodies also fluoresce, and the origin of this fluorescence is within the tube, as can easily be demonstrated.

'This influence penetrates objects opaque to ultra-violet light, sunlight, or arc light. Water and other like fluids, organic substances, such as paper, wood, and tissues of the body, are extremely transparent to it, while metals, inorganic salts, etc., are much less so; but no body is completely opaque. It is chiefly their density that affects the permeability of bodies. The rays have no calorific effect and are invisible to the eye. They are not deflected by prisms, nor reflected, refracted, or contracted by lenses. Bodies behave toward the rays as turbid media to light. The intensity of the fluorescent light varies nearly as the inverse square of the distance between the screen and the discharge tube. The air absorbs these rays much less than it does the kathode rays. The X-rays are not deviated by a magnet. The place of most brilliant phosphorescence of the wall of the discharge tube is the chief seat whence the rays originate and spread in all directions—*i. e.*, they proceed from the front, where the kathode rays strike the glass, and if the latter are deviated by a magnet, the X-rays proceed from the new point at which the kathode rays end.

'Of special interest is the fact that photographic dry plates are sensitive to these new rays. It is thus possible to exhibit this phenomenon so as to exclude the danger of error. I have thus confirmed many observations originally made with observations with the eye through the fluorescent screen. Here the power of rays to pass through wood or cardboard becomes useful. The photographic plate can be exposed to their action without removing the protecting case, so that experiments need not be conducted in darkness. A regular shadow picture is produced by the interposition of a more or less permeable body between the source of rays and the photographic plate or fluorescing screen."

The salient peculiarities therefore are:

That these rays produce no excitation of the optic nerve and are therefore invisible to the naked eye.

That they possess the power of traversing substances opaque to ordinary light.

That they possess the power of producing fluorescence in certain bodies upon which they strike.

That they are capable of affecting sensitized photographic plates.

The rays may be produced by the discharge from any source of sufficiently high tension, through a proper tube.

The Tube.

The Geissler tube, so well known to every student of physics, is a low vacuum tube, hermetically sealed, usually exhausted to about $\frac{1}{1000}$ of an atmosphere, into which project metallic terminals that may be connected with the poles of a source of electricity of high potential. In 1879 William Crookes, of London, devised a new form of tube having a high vacuum, the tube

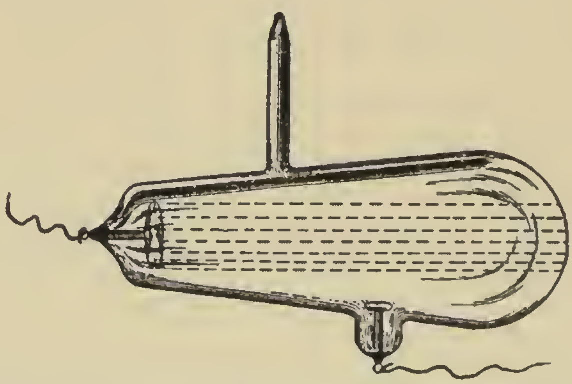

FIG. 150.—SHOWING THE COURSE TAKEN BY AN ELECTRIC DISCHARGE IN A CROOKES TUBE.

being exhausted to about $\frac{1}{1,000,000}$ of an atmosphere. If the terminals of a Geissler or low vacuum tube be connected with an influence machine, the poles of the machine and the poles of the tube corresponding, a band of light will be produced and the discharge will take place between the kathode and the anode; if, on the other hand, a Crookes tube be similarly connected, a fluorescence will set in, and the discharge from the kathode will pass in straight lines to the opposite wall of the tube, regardless of the anode, which is usually placed at any indifferent point on the side. (See Fig. 150.)

These kathode rays are generally believed to consist of streams of negatively electrified particles. This belief is supported by the fact that the rays are capable of deflection by a magnet.

At whatever point these kathode rays impinge, fluorescence and heat are produced, and it is this fluorescent part that is the seat, or origin, of the Röntgen rays.

In order to obtain as great a concentration of kathode rays as possible, and therefore a corresponding concentration of X-rays, a special arrangement of the tube must be made. The kathode rays could easily be focused upon a single point of the tube by making the kathode concave. But if the kathode were concave and the rays thus focused upon a single small part of the tube, the heat produced at this point would be so great as to fuse the glass. This is overcome by introducing, at the point upon which the focused kathode rays impinge, a piece of platinum foil (Fig. 151) placed at an angle. These rays are thus concentrated upon a small surface, the heating of which, it being platinum and not being

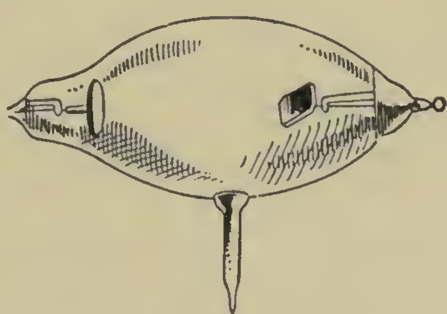

FIG. 151.—AN X-RAY TUBE.

in contact with the glass of the tube, in no way damages the latter. This piece of foil is called the antikathode, and becomes the source of the X-rays.

In all such focusing tubes the kathode rays are partially reflected from the antikathode and impinge upon the walls of the tube, and there also excite X-rays, which, however, do not interfere with the rays produced at the antikathode itself. Such tubes are constructed of various shapes.

The focus tube with adjustable vacuum is the latest development of this kind of tube. Such a tube is made by the Edison Manufacturing Company, and is shown in figure 152. It possesses the advantage over the ordinary focus tube of admitting of a lowering of the vacuum in the tube by shortening or length-

ening the space between the spark rods of the adjuster. Messrs. Queen & Co. make a tube (Fig. 153) in which the vacuum is adjustable and is kept constant at the desired point by means of an automatic device.

A reference to the illustration will make the operation of the tube clear. A small bulb containing a chemical that gives off vapor when heated, and reabsorbs it when it cools, is directly connected with the main tube, and is surrounded by an auxiliary tube exhausted to a low Crookes vacuum, the kathode being so placed as to heat the bulb by the bombardment of the kathode rays. This

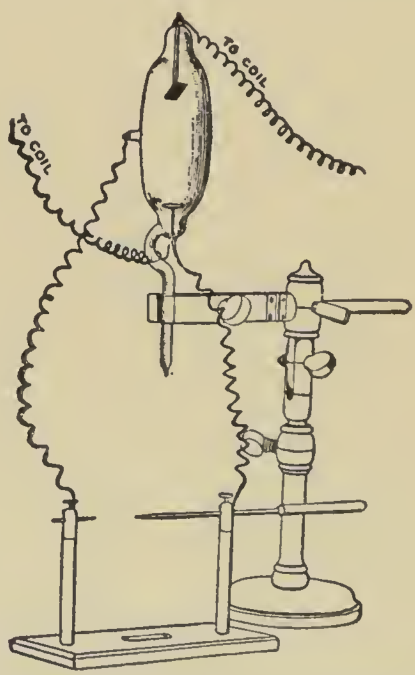

FIG. 152.—FOCUS TUBE WITH ADJUSTABLE VACUUM.

kathode is connected to an adjustable spark point, the end of which may be swung to any desired distance from the kathode of the main tube. The anode of the small tube is directly connected with the anode of the main tube. The coil is connected, as usual, with the main tube, which has been exhausted to a very high vacuum and consequently has a high resistance; the current, therefore, takes the path of least resistance by the spark point and the auxiliary tube, and heats the chemical in the small bulb, thereby releasing the vapor that it contains in state of absorption and driving it into the main tube. This will continue for a few

seconds until sufficient vapor has been driven into the main tube to bring down its resistance to that of the spark gap plus the small resistance of the auxiliary bulb, when the current will pass through the main tube. After this only an occasional spark will jump across the gap to counteract the tendency of the chemical to reabsorb vapor as its bulb cools, thus raising the resistance of the main tube. The tube is thus maintained at a constant vacuum while running. When the current is stopped, the chemical cools

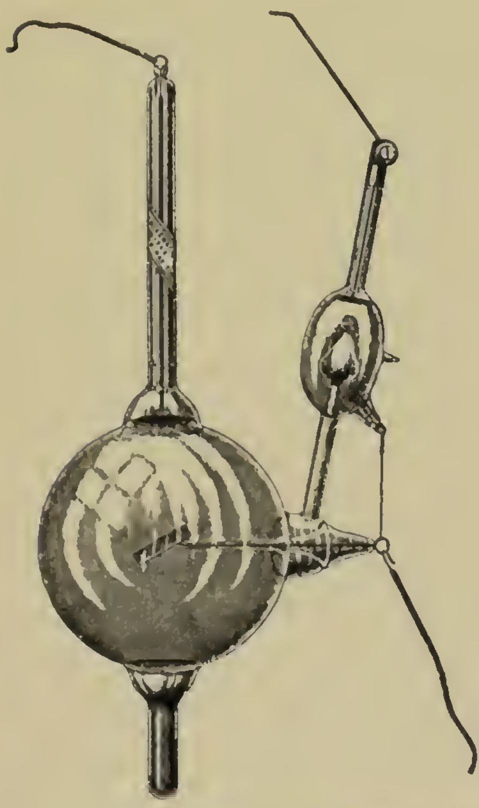

Fig. 153.—Queen Self-regulating X-ray Tube.

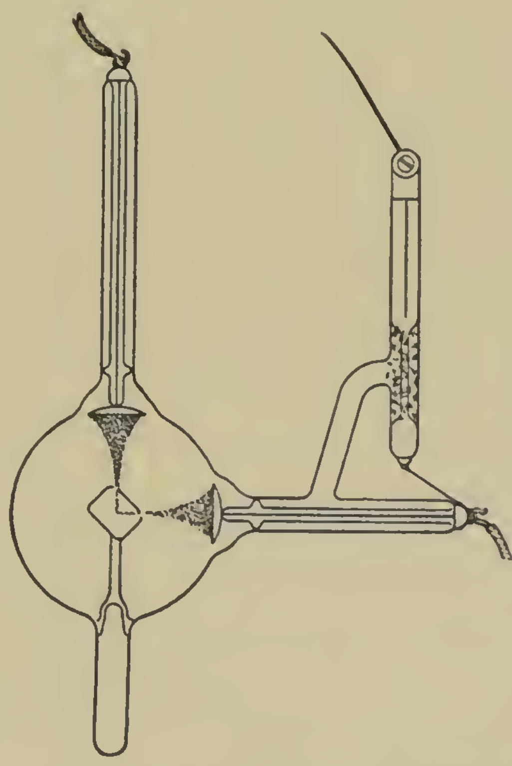

Fig. 154.—Automatic Adjustable Vacuum X-ray Tube, for use with Alternating Currents.

off and reabsorbs vapor, and the tube returns to its starting condition of high vacuum.

The tube may be set to run at high vacuum by placing the spark point at a considerable distance from the kathode terminal of the main tube, or to run low by placing it near the latter. A special form of tube on the same principle has been constructed for use with alternating currents (Fig. 154).

The adjustability of the vacuum is of the utmost importance, as

the penetrating power, photographic effect, and ability brilliantly to light a fluorescing screen all depend on the degree of exhaustion; and that degree of vacuum which is best for one operation is not so for another.

Exciting Current.

The next most important factor in the production of these rays is the apparatus necessary for the production of the exciting current. Currents from a high tension source are requisite. Such currents may be obtained from a powerful static machine or from a Ruhmkorff coil operated by the currents of a primary battery, secondary battery, or central station.

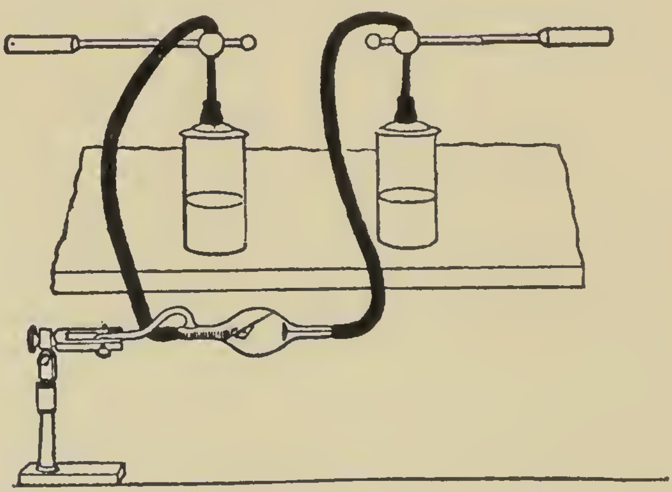

FIG. 155.—SHOWING THE ATTACHMENT OF X-RAY TUBE TO STATIC MACHINE.

If the **static machine** be used, the tubes should be connected directly to the prime conductors without the intervention of Leyden jars, as is shown in figure 155, but in my experience it has proved better that a spark gap, if possible an adjustable one, should be left between one pole of the machine and the corresponding pole of the tube. By means of this spark gap the discharge through the tube becomes oscillatory.

For the excitation of small tubes an influence machine gives fairly good results; but when powerful tubes are to be excited, it is necessary not only to employ machines with large plates, giving a spark of sufficient length, but the quantity of electricity also must be increased by a suitable increase in the number of plates. The

ampèrage of even the largest influence machines is, however, insufficient to enable us to obtain as satisfactory results as with a suitable Ruhmkorff coil, excited through a vibrator or revolving circuit breaker.

The **Ruhmkorff coil** to be used should be specially constructed for the purpose in view, for in the use of the high voltage that is necessary, the insulation between the primary and the secondary coil must be so perfect that under no circumstances can a spark discharge take place from the primary to the secondary coil. Such an occurrence is always due to the defective construction of the apparatus. The Ruhmkorff coil once set up, requires no special attention, particularly if the interrupter is, as it should be, separated from the coil and joined to the remainder of the necessary apparatus. The condenser may form one piece with the coil or may be separated from it. The induction coil may be operated by a primary or storage battery, by continuous electric-light circuit, or by alternating current electric-light circuit. In each instance the coil should be specially adapted to the source of the current. In all cases a switch for reversing the current is necessary, so that the kathode can be brought opposite the reflector in the tube.

Induction coils for use with X-ray tubes are usually estimated as to their strength by the secondary sparking distance, the greater sparking distance corresponding to a greater electric force, thus enabling a more powerful tube to be operated.

In addition the apparatus consists of: (1) An **interrupter**; (2) a **rheostat** for current regulation; (3) the **accessory apparatus** for transillumination and for facilitating skiagraphic impressions.

The Interrupter.—Various kinds of interrupters may be employed. A spring platinum interrupter is serviceable only with a coil giving a spark of not more than 25 centimeters, and then only with a battery current. The destruction of the platinum, in consequence of the unavoidable large spark passing between it and the adjusting screw, is so great and so rapid that very soon there is insufficient contact and consequent irregularity of action. A better interrupter consists of a metallic wheel attached to an electro-

motor ; this wheel is provided with gaps on its periphery upon which brushes rest, so that the circuit is interrupted a number of times during each revolution of the wheel.

When, however, a 110 volt continuous current is employed to excite the coil, some arrangement should be provided by means of which the sparks may promptly be extinguished, and thus the circuit be broken quickly. Figure 154 shows such an apparatus, known as the Edison instantaneous air-breaking wheel.

The device consists of two tooth wheels mounted upon the same shaft. The projections, or teeth, make contact with two flat brushes that bear on the outer peripheries, and by which the current is brought in and let out again. These wheels are rotated at a very high speed by a small direct current motor that also runs a

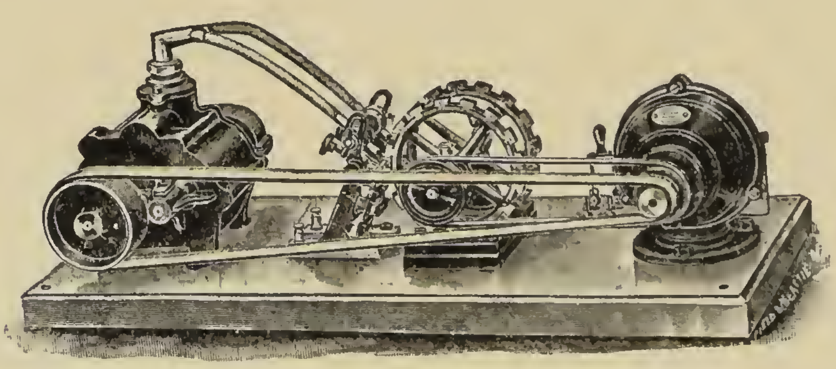

FIG. 156.—EDISON INSTANTANEOUS AIR-BREAK WHEEL.

pressure blower. The air blast from the blower enters a bifurcated tube, and is conducted to two flat nozles immediately over the contact brushes.

When the device is set in operation by starting the motor and connecting the primary pole of the induction coil in series with the binding posts provided for this purpose, the spark formed at the contact brushes, when the coil is energized, is blown out instantaneously by the air blast at the moment of formation. This greatly increases the rapidity of change in the magnetic circuit, and vastly augments the electromotive force in the secondary coil.

The **rheostat** to be used requires no special description ; it must, of course, be adapted to the current employed.

The Fluoroscope.—If, in a darkened room, an excited tube be

placed in a cardboard box into which no ordinary light can enter, no light from the excited tube will be seen on the outside of the box. If, however, one side of a screen of wood or cardboard be covered with some suitable fluorescent material, as barium platinocyanid or calcium tungstate, and this screen be held with its coated side to the eye of the observer, the screen will be seen to fluoresce, from the excitation of the X-rays that have passed through the box and the wood or cardboard of the screen. A metallic object held against the board of the screen, between this and the source of the X-rays, will intercept these rays and cast a shadow upon the active surface of the screen, so that the eye will see a dark shadow of the metallic object surrounded by a

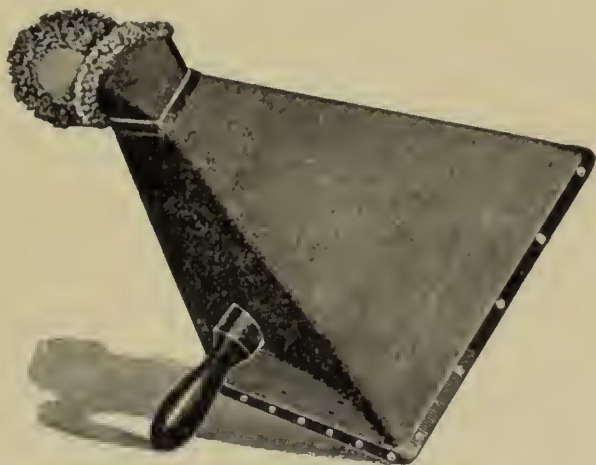

FIG. 157.—FLUOROSCOPE.

fluorescent field. Upon this principle the fluoroscope is constructed. It consists of a light-tight box (Fig. 157), very similar in shape to a stereoscope, the small end having an aperture and made to fit tightly over the eyes and bridge of the nose; the inner surface of the broad end is covered with a uniform layer of fine crystals of fluorescent material. This latter constitutes the fluorescent screen, and is the essential feature. If, now, the examiner place his eyes to the narrow end, and the extended hand be held against the broad end of the fluoroscope so that it comes between this and the source of the rays, the shadows of the bones of the hand, and less-marked shadows of the tissues, will be seen upon the screen instead of the general fluorescence.

The fluoroscope may similarly be applied to the examination of any portion of the body penetrable by the X-ray without prolonged exposure. By its use not only so-called surgical lesions, as of bones and joints, and the presence of bullets and other foreign bodies may be detected, but the thoracic viscera may be examined, and, with less satisfaction, the abdominal contents. It is of signal use in determining the size and position of the heart, the presence or absence of aneurysms (see Fig. 159) and other tumors of the mediastinum, the presence or absence of pleural adhesions and effusions, etc., and may in some cases render possible the very early diagnosis of pulmonary tuberculosis. In more advanced cases its revelations may confirm or correct the inferences drawn from percussion and auscultation.

Skiagraphy.—The taking of a skiagraphic reproduction on a sensitized plate by means of X-rays offers no difficulty. According to the necessity, the tube is so fastened in the standard that the rays take a horizontal or a vertical direction. Plates equally sensitive to ordinary daylight seem to be variously sensitive to the X-rays, and silver bromid gelatin emulsion plates seem to be best adapted to give the most satisfactory results. No camera is employed. The sensitized plate is secured in an ordinary plate-holder, or is completely enveloped in black paper. The object of which we wish to get a skiagraphic print is placed between the sensitized plate and the source of the rays, always being sure that the sensitized surface of the plate is nearest to the object to be reproduced.

The tube is set up at the distance best suited to its power, and this varies from one to three feet. The time of exposure will vary also according to the energy of the tube, and will depend upon the kind of plate employed and upon the thickness of the tissues to be penetrated by the rays. With a good apparatus, from fifteen to thirty seconds' exposure should suffice for the hand, from three to eight minutes for the hip-joint, and eight to ten minutes for the thorax or abdomen. The plate is then developed by the usual methods of photography.

A reproduction of a skiagram of the hand is shown in figure 158. This picture is taken from the right hand, with the palmar

Fig. 158.—A Skiagram.

surface toward the sensitized plate. At first glance it seems to be the left hand and not the right, but this is an error that must be guarded against. It is easily seen that in the developed plate the lights appear dark and the shadows appear light; so from the point of view of lights and shadows the plate is a negative, but in

Left. Right.

FIG. 159.—SKIAGRAM OF ANEURYSM OF THE TRANSVERSE ARCH OF THE AORTA.—(*Plate by Professor Arthur Goodspeed, from a case of Dr. S. Solis-Cohen's.*)

Above the shadow of the pericardial sac and its contents is seen the shadow of the aneurysm, involving especially the transverse portion of the aortic arch. Through the normal lungs the radiations pass unobstructed. The plate being placed over the sternum and the tube at the back of the patient, the relations of right and left in the picture are as if seen from behind.

all other respects the plate is a positive. The contours are absolutely reproduced in silhouette form. Therefore the print from this plate, although its lights and shadows are correctly reproduced, is a negative, or the reverse of the original outline figure.

Figure 159 shows an aneurysm of the transverse arch of the

aorta.[1] Pelvic tumors, renal calculi, and other abdominal lesions have been demonstrated in a similar way.

Radiographic Table and Localization Apparatus.

Various appliances ordinarily at hand can be utilized for holding the tubes and for placing the patient in position for skiagraphic and fluoroscopic examinations ; but adjustable standards and tables specially designed for the purpose are supplied by manufacturers and greatly facilitate the work. Especially are these appliances desirable when it is necessary accurately to locate foreign bodies, calculi, tumors, etc. Messrs. Queen & Co., of Philadelphia, have built for the Polyclinic Hospital of that city, after suggestions of Dr. C. L. Leonard, a radiographic table, the use of which is shown in figures 160 and 161. It is made in two sections, each three feet in length, together with a small foot-board. Both the foot-board and one length of the table are adjustable at various angles to the horizon, in order to admit of adaptation to different cases. The top of the table is of thin fiber sheet, which is very tough, and at the same time transparent to the X-rays. The plate-holders consist of removable backs, four in number, eighteen inches long and fifteen inches wide, having a perfectly flat top surface. The tube can be placed in any position above or below the table, and if the plate-holders be removed, it offers an excellent method of fluoroscopic examination.

In localizing a foreign body, calculus, or other object in the body, it is a simple matter to take one picture, shift the position of the tube, change plates, and take another picture, without in any way disturbing the patient. The localization apparatus shown in figure 162 is employed, and from the different positions of the shadows of the ball of the indicator and of the foreign body on the two plates, the location of the latter is calculated. For the localization of foreign bodies in the eye, Dr. W. M. Sweet, of Phila-

[1] The case, occurring in the practice of the editor, was of great interest, as with the exception of localized dullness at the upper portion of the sternum, the usual physical signs of the condition were absent. The peculiar character of the cough suggested fluoroscopic search for aneurysm, and a permanent record of the findings was made in the skiagram.

delphia, has devised a special method, the application of which is shown in figure 163. Two radiographs are made, to give different relations of the shadows of the indicators and of the foreign body:

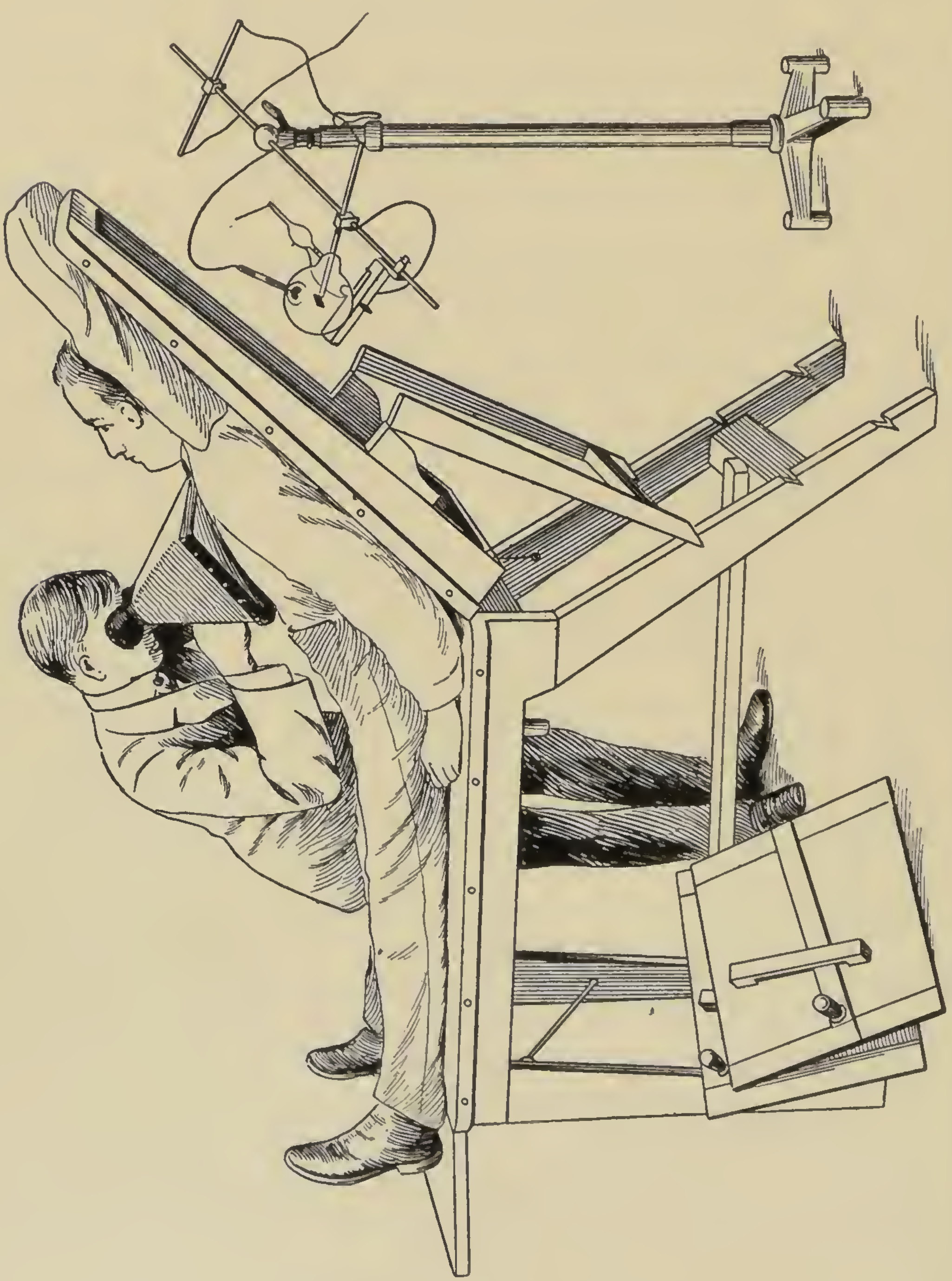

FIG. 160.—LEONARD'S POLYCLINIC ("QUEEN") RADIOGRAPHIC TABLE. EXAMINATION OF THORAX WITH FLUOROSCOPE.

one with the tube horizontal, or nearly so, with the plane of the indicators, and the second with the tube at any distance below this plane. Two circles are drawn, one to represent a horizontal, and

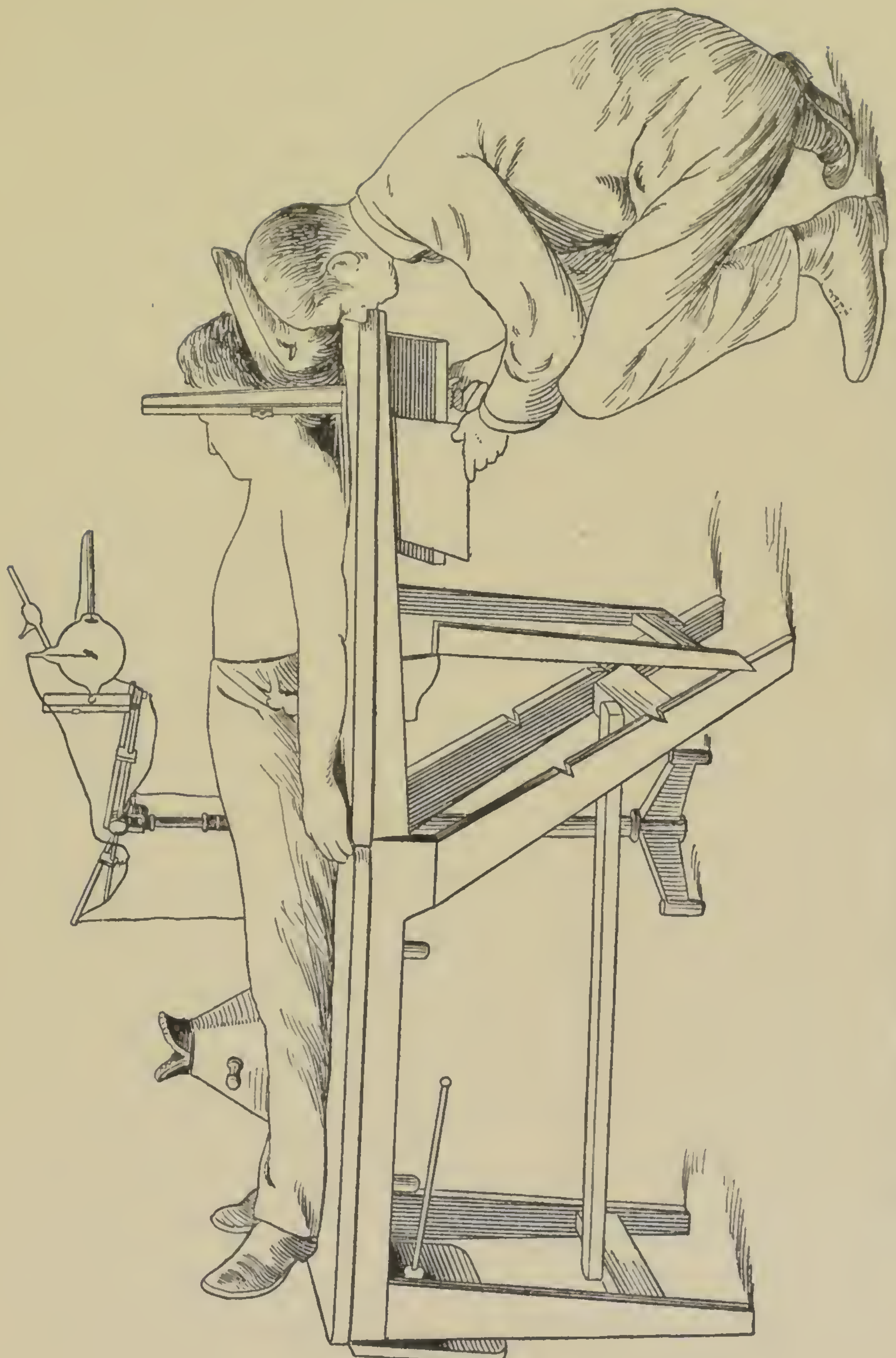

Fig. 161.—Leonard's Polyclinic ("Queen") Radiographic Table. Insertion of Plate.

the other a vertical, section of the normal eyeball, and upon these circles are noted the relative position of the indicators when the exposures are made. If measurements of the positions of the shadows of the indicators, as shown upon the plates, are entered upon these circles, and lines drawn through the points of measurement, the position of the foreign body in the eye must be at the crossing of these lines, representing the planes of shadow of the two exposures.

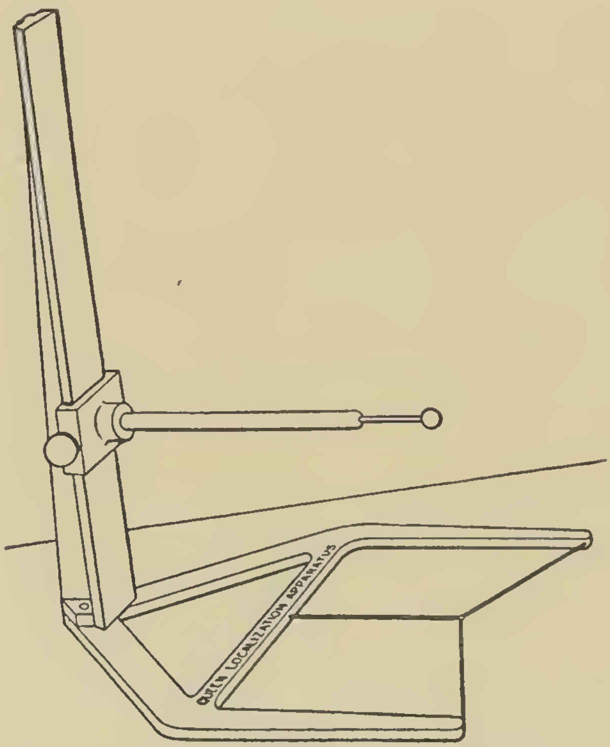

FIG. 162.—LOCALIZATION APPARATUS.

X-ray Dermatitis.—This is the most convenient place to introduce a necessary word of caution. Irritation of the skin, inflammation, and even extensive and severe burns may result from too prolonged exposure to the X-rays. These accidents were more common in the early days of skiagraphy. They are to be avoided by care as to the duration of the sitting and as to the distance of the tube from the body of the patient. The longer the necessary duration of the exposure, the greater should be the distance between the tube and the body. Some observers state that severe burns occur only when tubes of low vacuum are used. Others interpose an

aluminum screen between the tube and the patient and claim thus to avoid the liability to produce burns.

Some persons manifest a peculiar susceptibility to the caustic action exerted by, or accompanying, the Röntgen rays, and this cannot be predetermined; so, also, the very young, the aged, and the debilitated are less resistant than others. In the absence of special idiosyncracy in persons of average strength thirty minutes may be considered the maximum duration of exposure, and

FIG. 163.—DR. SWEET'S APPLIANCE FOR LOCALIZING FOREIGN BODIES IN THE EYE.

ten inches the least distance of the tube from the body, permissible. A number of exposures at brief intervals should be counted as one in estimating time. As the burn is not usually evident until two or three days after exposure, prolonged sittings should not ordinarily be repeated without an interval of at least forty-eight hours.

No satisfactory explanation of the irritant influence of the radiation has been given, but attempts have been made to utilize it, under proper control, in therapeutics.

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